AC/243 (Panel 8) RSG-18 on Operator-Robot Interaction

WORKSHOP ON CRITICAL ORI ISSUES
Bordeaux, France
27-29 October 1992

SUBGROUP TERMS OF REFERENCE

Introduction

A number of scientists, engineers, military users and procurement officers from seven NATO countries have been invited to attend and contribute to the RSG-18 workshop in Bordeaux. Each guest has been selected for the knowledge or skill they can bring to a particular subject and, on this basis, guests have been assigned where possible to the most appropriate subgroup (SG) for the detail of the workshop. The five SGs were conceived in a standard format, each trying to give the appropriate answers to the following fundamental questions:

- What are present operator-robot interaction (ORI) techniques?
- How do comparable ORI techniques affect operator performance?
- How do these techniques relate to the possible missions?
- Which unresolved ORI issues are potentially solvable in the next 3-5 years?

It is now clear that, with the wide range of experience brought by the guests, different SGs are likely to have a different style and emphasis. Whilst by no means abandoning the fundament questions above, the subgroups' Terms of Reference (TOR) have been reformed to better reflect the composition of the groups and the expectations of the workshop as a whole.

In reading the TORs below, it is important to remember that all three 'domains' of land, air and sea operations are embraced by each subgroup in this workshop, and the exact wording should be modified to suit the environment in question.

WORKSHOP SCHEDULE

Day 1 - 27 October 1992

Introduction

0830-0845	Welcome, RSG Background, Goals of Workshop - Dr. Hodge
0845-0900	Welcome, Administrative Arrangements - Mme. Fargeon

National Presentations

0900-1000	Belgium - Prof. Baudoin
1000-1030	Break
1030-1130	Canada - Dr. Grodski
1130-1230	France - Mme. Fargeon
1230-1400	Lunch
1400-1500	Germany - Dr. Holzhausen
1500-1600	Netherlands - Dr. Passenier
1600-1630	Break
1630-1730	United Kingdom - Mr. Humble
1730-1830	United States - Dr. Hodge

Subgroup Orientation

1830-1900	Subgroups meet for instructions

Demonstration Videos

2100-2200	Video presentations

Day 2 - 28 October 1992

Subgroup Activity

0830-1000	Subgroup deliberations
1000-1030	Break
1030-1230	Subgroup deliberations
1230-1400	Lunch
1400-1530	Subgroup deliberations
1530-1600	Break
1600-1800	Subgroup deliberations

Dinner

1900	Prestige dinner

Day 3 - 29 October 1992

Subgroup Activity

0830-1000	Subgroup deliberations
1000-1030	Break
1030-1230	Subgroup report preparation
1230-1400	Lunch

Subgroup Reports

1400-1430	Subgroup 1 report
1430-1500	Subgroup 2 report
1500-1530	Subgroup 3 report
1530-1600	Break
1600-1630	Subgroup 4 report
1630-1700	Subgroup 5 report

Concluding Session

1700-1730	Wrap-up summary
1730	Adjourn

[redacted]

Subgroup 1 - Military Applications and Operational Validation

Co-chairs: Dr. Catherine Fargeon, France
Prof. Yvan Baudoin, Belgium

Guests: Lindsay, Canada
Quin, France
Schilling, Germany
Mitchell, UK
McDonald, US
Smith, US
Weiland, US

This group contains a number of military users and guests from the area of operational test and evaluation. Broadly, the group is less likely to be aware of, or expert in, ORI matters at a scientific level, but in likely to be familiar with 'real-world' environments and the current, practical, limitations of both human operators and military equipment, and the difficulties of assessing the performance of both.

The SG will act in some ways as a focus for other groups' activities since they will be looking at the fundamental question of military missions, without which the other discussions are fruitless.

Specifically, SG-1 will discuss:

- What do users want robots to do?
- Possible mission scenarios for robot systems.
- Simulation and training facilities.
- Methods of assessing overall system performance.
- Interoperability of robotic systems across NATO.
- Limitations of transmission media on operations (radio, fibre, fallback modes, etc.).

EXPECTED OUTCOME:

THE SUBGROUP WILL BE EXPECTED TO SUGGEST A LIST OF PRIORITY MISSION SCENARIOS AND A STRATEGY FOR ROBOTIC OPERATIONS AND OPERATIONAL PERFORMANCE ASSESSMENT.

Subgroup 2 - Planning, Navigation, and Function Allocation

Co-chairs: Dr. J.-P. Pouplard, France
Dr. Peter Passenier, The Netherlands

Guests: Leysen, Belgium
Chesney, Canada
Barrouil, France
Scriven, UK
Smootz, US
Hamel, US

The experts in this group will broadly be discussing the medium and high level information required at the operator-robot interface (ORI). As technology grows more sophisticated, the degree of involvement of the operator reduces toward autonomous vehicles. However, the criticality of the remaining human decisions tends to increase. This will be a factor in deciding which tasks are best performed manually, and which automatically (i.e., 'function allocation'). From this, the technology and particularly the ORI issues associated with high level planning (mission planning) and intermediate level planning (local navigation) can be discussed, and possible solutions found for each level of autonomy.

Specifically, the SG will discuss:

- Which tasks are best suited to automation.
- Degree of control: teleoperated/supervisory/autonomous.
- Information required to plan 'human-in-loop' missions.
- Information required to plan 'autonomous' missions.
- Requirements of prior databases (including maps, geographical data, threat data, meteorological data).
- Navigation aids: Requirements of position fixing systems.
- Special requirements of multi-vehicle control/supervision.

EXPECTED OUTCOME:

THE SUBGROUP WILL BE EXPECTED TO IDENTIFY CURRENT LIMITATIONS ON ROBOTIC DEPLOYMENT DUE TO TECHNOLOGY OR INADEQUATE PRIOR DATA, AND AREAS IN WHICH INTERMEDIATE AND HIGH LEVEL O-R-I RESEARCH IS REQUIRED.

Subgroup 3 - Vehicle Man-Machine Interface (High Bandwidth)

Co-chairs: Dr. Peter Holzhausen, Germany
Dr. David Hodge, United States

Guests: Milgram, Canada
Borredon, France
Graefe, Germany
Bartha, Germany
Stone, United Kingdom
Brendle, United States
Dees, United States

This SG is the first of three groups dealing with the low-level design of the operator-robot interface. This SG should assume that a high bandwidth, error-free transmission medium is available between the remote vehicle and the control centre, as might be the case with a tethered system, or one employing a directional microwave link. Whilst the SG may note the operational limitations of such a link, it is not the intention that they should spend time debating the availability of that link in a military environment.

A further constraint on this group is that they should focus their work on the task of 'placement' or 'driving and manoeuvrering the vehicle'. The ORI matters pertaining to task execution once the vehicle is in place are referred to SG-5.

Specifically, the SG will discuss:

- Design of high bandwidth workstation/driving station.
- The relative impact on operator performance of various display features.
- Relative benefits of different sensory data, e.g., vision, kinaesthetic, audio, vestibular.
- For vision: field of view, steerable/zoomable cameras, stereo.
- Telepresence for placement.

EXPECTED OUTCOME:

THE SUBGROUP WILL BE EXPECTED TO CONCLUDE ON THE PRIORITY DESIGN FEATURES OF A HIGH BANDWIDTH TELEOPERATED DRIVING STATION, AND ESTABLISH WHICH OF THOSE ELEMENTS, IF ANY, REQUIRE FURTHER RESEARCH. IF THE SUBGROUP CANNOT REACH FIRM CONCLUSIONS, O-R-I RESEARCH SHOULD BE RECOMMENDED TO ADDRESS THE UNCERTAINTIES.

Subgroup 4 - Vehicle Man-Machine Interface (Low Bandwidth)

Co-chairs: Mr. Thomas Haduch, United States
Mr. Mark Humble, United Kingdom
Mr. Larry Peterson, United States

Guests: Acheroy, Belgium
Clement, France
Charles, France
Zapp, Germany
Boumans, The Netherlands
Van Kampen, The Netherlands
Barrett, UK
Roerhrig, US
Burt, US

This SG has very similar TOR to that of SG-3. It also is restricted to driving and manoeuvering, rather than task execution but, in this case, over a low bandwidth transmission link. The definition of 'low bandwidth' is not exact -- certainly visual images could not be transmitted without significant loss of quality. Data rates of 16 kbit/sec are often quoted since this is the typical rate available on military tactical radio systems. The massive image compression required to transmit over such links introduces a new range of ORI problems that this group should address. The operational implications of using low bandwidth links should be noted, but not dwelt upon.

Specifically, the SG will address:

- Image compression techniques and their merits.
- Workstation design.
- Information display techniques for video and other data.
- Latency in control, images and frame rate.
- Alternative/additional sensory feedback.
- What is the most effective use of available bandwidth?
- What are the implications for on-board processing and supervisory control?
- What is the effect of these methods on operator performance?

EXPECTED OUTCOME:

THE SUBGROUP WILL BE EXPECTED TO INDICATE WHETHER LOW BANDWIDTH TELEOPERATION IS A FEASIBLE OPERATING MODE, AND IN WHAT CIRCUMSTANCES IT MAY BE USED. THE SUBGROUP WILL IDENTIFY THOSE AREAS OF O-R-I RESEARCH THAT NEED TO BE ADDRESSED IN ORDER TO MAKE BEST USE OF THE AVAILABLE LOW BANDWIDTH INFORMATION.

Subgroup 5 - Mission Module Man-Machine Interface

Co-chairs: Capt Ronald Julian, United States
Dr. Julius Grodski, Canada

Guests: Preumont, Belgium
Imbert, France
Moliner, France
Le Moine, France
Carr, UK
Swinson, US

This group will comprise a balance of military (user) personnel and technologists, brought together to discuss the actual task or mission that the remote vehicle has been sent to perform, and the impact on the operator of performing tasks remotely. The SG will start from a list of generic missions that might be performed remotely. They are not constrained to discussing either high or low bandwidth transmission links, although they should be aware of the approximate data requirements for various information types, and be able to judge whether certain operations are feasible over low bandwidth links.

Specifically, the SG will discuss:

- Mission module components required for various scenarios (manipulators, sensors, cameras, etc.).
- The type of information that needs to be transmitted for the teleoperator to best perform the task.
- Shortfalls between mission requirements and mission capabilites.
- Display and monitoring requirements.

EXPECTED OUTCOME:

THE SUBGROUP IS EXPECTED TO LIST THE TECHNOLOGY REQUIREMENTS FOR REMOTE OPERATIONS, LIST THE CURRENT SHORTCOMINGS, AND RECOMMEND THE THRUSTS FOR FUTURE TECHNICAL AND O-R-I RESEARCH REQUIRED TO OVERCOME THOSE SHORTCOMINGS IN THE NEXT 3 TO 5 YEARS.

Expectations from the Workshop

Up to the present time, RSG-18 has performed a variety of analytic tasks. A microstructure list of possible operator-robot interaction (ORI) issues has been developed, and these have been put into core issue groupings. National program summaries have been exchanged and prospective robotics missions have been identified for each of the three domains. Now the RSG-18 invites national experts (i.e., invited guests) from the user and technology communities to assist it in identifying the key unresolved ORI issues which are critical to robotics progress over the next 10 years.

The national user and technology experts are expected to be able to reach consensus about the most important ORI issues in each of the five subgroups' topics, taking into consideration the various potential robotic vehicle missions and the relative degree of human intervention (teleoperation vs. autonomy) involved in robotic systems.

The subgroups are expected to present their conclusions in some systematic way, keeping in mind that RSG-18 has to distill from their conclusions some specific recommendations to Panel 8 about follow-on multi-national ORI research. Recommendations specific to each of the operational domains (i.e., land, air, sea) would be very helpful to RSG-18.

Finally, and most importantly, the guests are expected to conduct their deliberations in a friendly and harmonious way. Robotics is an **emerging technology**: there is as yet no 'best way' to design robotic systems, and no best operator-robot interfaces. Differences of opinion are expected to be expressed, and the discussion of different points of view is essential to arriving at some conclusions and recommendations about key issues.

The afternoon of Day 3 will be devoted to reports from the five subgroups: 30 minutes will be allotted for each subgroup. Anyone who wishes to take issue with the report of any subgroup may submit written comments or rebuttal to the Chairman within one week after the workshop. Those comments will be considered for inclusion in the RSG-18 final report.

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POSITION SUMMARIES

This enclosure consists of the invited guests' position summaries that had been received at the time of printing. If further summaries are received before the workshop, they will be reproduced and distributed in Bordeaux

Enclosure 3

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SUBGROUP 1

MILITARY APPLICATIONS AND OPERATIONAL VALIDATION

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1

Lieuten?nt-Colonel J. Graham Lindsay, CD

Classification

Land Electrical and Mechanical Engineering

Current Appointment

Since May 1990 LCol Lindsay has been a Section Head in the Directorate of Land Armaments and Electronics Engineering and Maintenance, within the National Defence Headquarters in Ottawa.

His section is responsible for the acquisition and in-service support of surveillance and target acquisition equipment including all optical, electro-optical (image intensification, thermal imaging and lasers), ground surveillance radars and other non-air defence radar equipment used in the Canadian Army. In addition it also supports the time keeping equipment and the limited amount of robotic and meteorological data acquisition equipment used by the Canadian Forces.

LCol Lindsay is part of the Canadian delegation to the NATO Army Armaments Group (NAAG) Panel VI, which attempts to monitor NATO and national projects and programs associated with Surveillance, Target Acquisition, Night Observation, Counter-Surveillance and Electronic Warfare equipment.

Academic Qualifications

Bachelor of Engineering in Engineering and Management, Royal Military College of Canada, 1970

Military Education

Canadian Forces Land Command and Staff College, Kingston, Ontario, Course 7901, in 1979
British Army Staff Course, Division 1, the Royal Military College of Science, Shrivenham, England, ASC 10, in 1981
Canadian Forces Command and Staff College, Toronto, Ontario, CSC 15, in 1985

Past Employment

LCol Lindsay served in Chilliwack, British Columbia from 1970 to 1973 and in Germany with 4 Canadian Mechanized Brigade Group from 1973 to 1976, in a variety of platoon and company level appointments as a Logistics Officer.

He reclassified to Land Electrical and Mechanical Engineering in 1976 and served in the Base Maintenance Company supporting the Combat Training Centre in Gagetown, New Brunswick from 1977 until his promotion to Major in 1979. During this period he served with the United Nations Disengagement Observer Force (UNDOF) on the Golan Heights from January through July, 1978.

Following his course in England he was employed as the Systems Engineer and Deputy Project Manager of the Small Arms Replacement Project, which acquired new rifles for the Canadian Forces, in Ottawa, Ontario, from 1981 until 1984.

Upon completion of Staff College in 1985, he commanded the Maintenance Company of 1 Canadian Brigade Group in Calgary, Alberta.

He was promoted to LCol in 1986, and until 1990, was employed in Ottawa, Ontario, as the Integrated Logistics Support Manager for the Tactical Command Control and Communications Systems Project, involved with the acquisition of new combat net radios and other communications equipment.

I have served as an Army officer for the last 26 years, in a variety of command and staff appointments. My field experience has been in a number of positions from assistant platoon commander to company commander, all in logistics support units, involved with transportation, re-supply and the repair of tactical equipment. I have also been employed in a base environment in support of Army activity, with similar responsibilities, but in non-tactical units. I served for a six month period with the United Nations on the Golan Heights.

Most of my staff appointments have been associated with the procurement of new army equipment, including vehicles, tactical radios, rifles and machine guns, and surveillance equipment. To a very small degree, this has included some tele-operated and basic robotics equipment. These responsibilities included being a project sponsor and military advisor for Canadian government research and development establishments and portions of our industrial sector. Some of this activity has been with sensor systems and, to a lessor degree, with control mechanisms. Throughout this activity I tried to ensure that the soldier receives what is needed to do the job -- quickly, safely and efficiently if possible.

My academic qualifications are limited: a bachelor of engineering degree in Engineering and Management (a combination of industrial engineering and operations research), graduated from two different Canadian Army staff college courses, and I spent a year completing the technical portion of the British Army Staff Course, at the Royal Military College of Science, Shrivenham.

The most significant asset I can bring to the RSG 18 discussions on critical issues in robotics is my opinion, which I have been known to express, usually in a less than pig-headed fashion.

I am a firm believer in robotics and its ultimate application in performing Military roles. However I am convinced that the acceptance process will be long and difficult, for three primary reasons: the extremely conservative and parochial thinking of military leaders who are the decision makers, the economic pressures that make the pursuit of robotics related technologies difficult to support in the face of other needs and the perceived lack of progress towards satisfactory capability given popular expectations for robotics.

Foremost the military man considers himself a leader of men. To give a military leader robotics capability instead of men can be a direct personal challenge, not only to his self perception as a leader of men, but potentially to his ability to complete the variety of tasks that he (or she to be fair) may be required to complete. Those who have served in a commanding role in a military organization know the value and flexibility of manpower that is available 24 hours a day, can perform any task, seemingly at the whim, but certainly at the will of the leader. Robotics systems are perceived to be limited in flexibility --rule bound and inflexible. The key here is the flexibility of the soldier -- perhaps a robotic sentry that can also serve drinks in the Officers' Mess before dinner would be a more sellable commodity. Perhaps I have been too flippant in my example. Flexibility is one of the principles of war, codified by von Clausewitz and often repeated since. At its foundation throughout history is the reliance of military leaders on a mass of men to perform the task at hand. When you tell a military leader that a robotics system can save manpower he is not genuinely interested, because he does not want to save, or, as he sees it, sacrifice manpower for something less flexible, and hence less capable. This reluctance is reinforced by observations that the military decision maker has made: that successful robotics applications in industry have been in very controlled environments, performing limited

and extremely repetitive tasks, and that more ambitious projects have faced criticism and often condemnation because they have failed to overcome obstacles in unstructured environments. A military man is familiar with unstructured environments, although he may not immediately recognize that specific term. That such judgments are made with little regard as to how a manned system would have performed in similar circumstances, especially had the operator been less that well prepared for the task at hand, is irrelevant.

The lack of funding priority for robotic applications may not be a reason in itself but, if not, it is at least a consequence of the lack of sponsors who are committed to robotics as a solution to military problems. Having a number of technology areas and differing types of equipment to support, every day I see the problem of trying to champion low visibility equipment . In our Department of National Defence, and I'm sure the same is true for all, it is the high visibility hardware; things that produce direct kills, that seem to get funding support out of all proportion to what I perceive is its relative importance to an Army. Thus we have the helicopter gunships, the tanks and the rifles that are funded. The surveillance devices, water trailers, generators and sleeping bags have a much more difficult time. Most "acceptable" robotic applications seem to fall into a category similar to the surveillance devices. This categorization is in part because I have yet to find a military decision maker who is willing to trust an autonomous machine that can kill. Hence the proposed use of robotics is often in a less controversial role.

Finally I want to discuss the problem of achievement, or the perception of the capability of current technology. Unfortunately robots have been the stuff of science fiction, in print and on screen. Real life robotic systems, unless confined to very controlled environments, appear to fall far short of the abilities of their fictional forebearers. We thus face the very exasperating situation in which the technology is perceived, by those who hold the purse strings, as not being able to do the job. This situation is not at all helped when, for various but the wrong reasons, high technology associated with robotics is attacked and ridiculed. Two such cases that come to mind are the USS Vincennes, which downed the Air Iran passenger liner during the Iran - Iraq War, and the very recent condemnation in the US media of the Patriot missile system, whose performance during the war in the Persian Gulf was exaggerated for propaganda's sake. In both cases I suspect the truth lies somewhere in the middle, but the common man finds it much easier to remember the sensational, especially that which casts doubt on the capability or the advisability of relying on emerging technology.

However the Workshop is not intended to be a negative environment, and I did not offer these points to be a nay-sayer. I think that roles for robotics, particularly those proposed for initial fielding, must recognize these realities. To be successful, we must seek to avoid these pitfalls. The problem then is simple -- just find a non-threatening, benign and inexpensive application, and make it work perfectly. What could be easier?

Lieutenant Colonel Graham Lindsay

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ANNEX A TO
D/LSOR 5/41/7/3
DATED 6 Apr 92

Lt Col D C Mitchell RE - UK MOD Land Systems Operational Requirements - Position Summary

1. Within UK, teleoperated land vehicles have been used for a number of years in counter-terrorism and similar roles but robotic systems currently have no true battlefield applications.

2. The UK applied research programme acknowledges this position and supports an evolutionary approach technically and operationally. The MARDI demonstrator vehicle is nearing completion and will be used to develop operational concepts as well as to further technical goals.

3. Lt Col Mitchell is a member of the Operational Requirements (OR) staff within MOD and has been appointed as the "focus" for research for robotic land vehicles. Prior to the creation of a focus, the research programme attempted to meet the diverse and uncoordinated requirements of several OR branches.

4. In revising the research objectives, it was felt important to keep in mind the possible applications for robotic vehicles. To this end a survey was undertaken of OR branch aspirations for robotics. The results of this survey will be prioritised by operational and technical criteria and will form the basis of future short and long term research policy.

5. One of the principal obstacles to the successful exploitation of the capabilities of robotic vehicles is seen as the lack of user awareness and confidence. In addressing this, it will be necessary to measure the probable effectiveness of systems on the battlefield and to estimate their cost effectiveness compared with manned alternatives.

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TITLE: Verification and Validation of Combat Models
A Realistic View.

AUTHOR: John R. Robbins
Technical Solutions, Inc.

Introduction:

There is little argument within the Military Operations Research Community as to the importance of establishing the credibility of the "tools", mostly simulation models by which analyses of combat related issues are conducted. And, the scientific approach to establishing such credibility is reasonably well defined in the process commonly referred to as "Verification and Validation." Yet, the argument (in its kindest form) has continued throughout the years as to whether or not one can truly verify and validate a model of combat. Moreover, for that part of the process which it is generally agreed can be accomplished, questions abound as to the relative trade-offs of cost versus level of verification/validation and whether the process should be formal or informal. This discussion focuses at a conceptual level with these issues and suggests a position relative to the verification and validation process within a framework of reasonable expectations on the part of the combat model developer.

The Verification Process:

Our friend, Webster, defines verification as,

> *"the establishment or confirmation of the truth of a fact, theory etc."*

We in the OR community have come to interpret this as the process of determining that a model "behaves" as it is represented by the developer. This is neither a simple nor trivial process. But, at least it can be done. And, it is important to distinguish verification from validation. In truth, a model can "pass" the verification process, yet fail miserably even the most rudimentary validation tests. Obviously, some definition to the term "behaves" is needed to establish a reference for examination of the verification process. While many of our contemporaries often blend the issues of verification and validation together -- some steps of each in the other, a preference is to establish each process as an independent set of issues, both of which must be addressed. Verification is then viewed as a rigorous examination of the inputs, internal processes, and methodology implementation within a model, including:

- process testing from the algorithm level to the full process level,
- use of verifiable test data,
- for computer models, execution of adequate debugging and testing procedures to ensure proper data flows, event sequencing, and compilation of statistics as intended in the design,

- comparison of test results, where possible, with external sources.
- sensitive analysis of key model parameters and evaluation of the statistical convergence of stochastic processes.

It is important to note that at the conclusion of the verification process one has not established the usefulness as a prediction tool of a model nor "graded" it as a good or bad representation of the combat phenomena it was designed to replicate. It has simply been established that the model behaves as represented.

One of the disturbing trends that we see today in addressing the issue of verification is that of the growing government emphasis on an "independent" verification process and efforts to formalize the procedural process for verification. While it is commendable that the value of a good verification process is recognized, burdening the combat model developer with additional high costs of formal, independent verification can only force the ownership costs of combat models even higher and, thereby, reduce the population of end users-- be they defense contractors, universities, or organizations within the government itself.

The verification process can, and should, be improved, but the model developer must be responsible for the verification process as an integral part of the development effort, and, he must be able to afford such a process. While some guidelines are certainly available to assist the developer, these can and should be significantly improved, documented, and distributed. Who should accomplish this chore is not entirely clear-- perhaps MORS, IEEE or similar industry professional organizations are more appropriate than the government.

As to expected standards applied to verification, it is not clear that a formal independent process is necessary, except in rare instances where the developer feels justified in the expenditures associated with independent verification. In practice, it is more the reputation and credibility (or lack thereof) established by peer review and acceptance of the model results by end users that forces the model developer to reasonable standards of verification than dictated formal procedures and independent review.

Scarce resources are best spent on documentation of the combat model (there presentation of model design and implementation of that design). The review process must begin with the implicit assumption that the developer has done a conscientious implementation to include verification. Users and/or reviewers of the model and results of its use, then have a basis (the formal documentation) for questioning the implementation methodologies and processes within the model. Similarly, peers within the OR community with particular interests in a model have a basis for accepting or challenging the model from a viewpoint of how well it has been "verified."

The Validation Process:

Unfortunately, the validation process is neither as conceptually or scientifically straight forward as the verification process. Nor is it realistically achievable at any but the most basic levels of combat modeling representation, principally those that represent engineering level system and performance data which can be "compared" directly with test data collected under rigorous "bench tests."

Of course, Webster expects a great deal more in defining validation as,

> *"the determination of the degree of validity of a measuring device:... to support or corroborate on a sound or authoritative basis, experiments to establish a hypothesis."*

In our case, completing the validation requirement in its entirety would establish that a particular combat model adequately represents real combat to the degree that the model can be used to forecast combat outcomes. Over the many years that the OR community has wrestled with the issue of validation of combat models, there have been many, many attempts at developing and demonstrating a credible validation process in its most global sense. Many of these have been "interesting", most have not, and unfortunately, many have been misleading. And, virtually all have failed the test of "peer examination." As a result, the OR community is left with several effective, but sub-optimal approaches to the validation issue. When examined carefully, they, of course, do not meet either a rigorous or totally satisfactory validation test. However, they are the only realistic approaches and are generally categorized as;

- validation of subcomponents of a model, where validation is possible at the lower level, with the implicit assumption that validation of some (not all) components offer a "degree" of validation to the overall model,
- comparison with industry standard models that by virtue of the developer credentials, extensive verification processes, and user acceptance of the results of these models represent "accepted" models, and
- comparison with instrumented field trial data of unit and system combat tests.

Each of these approaches (preferably a combination) offers the developer a validation tool in the ultimate search for credibility. However, as one progresses from a subcomponent approach, to model and field test comparisons, costs rise rapidly-- more exponential than linear. And, the availability of "benchmarks" decreases. As a result, virtually all model developers except those government agencies with major model development budgets are forced to one of two positions;

- very limited validation efforts, or
- no validation effort.

In the end, only a tiny fraction of all combat models actively in use have completed what could be considered reasonable validation steps. In fact, there are probably fewer than a dozen important models that meet the test of reasonable validation.

Unfortunately, the problem of limited validation is not solved by increased government emphasis on validation. Rather it compounds the problem by pressuring developers to either misrepresent validation efforts or to abandon their model development efforts in favor of the very limited set of models that have gained "government acceptance." Were these few models truly valid, such a

direction to reduce the number of models applied to combat issues might be useful. We could all use the same models, get the same answers to comparative issues, and recommend the same solution to a combat problem. But what if these few "accepted "models are not valid?

For certain, we need improved approaches to the verification and validity processes for combat models, but the solution lies in lowering the resource costs of conducting reasonable model testing rather than in reducing the number of models or discouraging new model development. And, the costs can be reduced by a consolidated effort to establish repositories of "benchmark data" that is available to the combat developer during the verification and validation period of model development. Without providing a solution to unrealistic costs and continuing the current trend of insistence on demonstration of verification and validation programs in the model development process, we will move backwards--not forward in combat modeling.

ABSTRACT

RESEARCH STUDY GROUP 18 on OPERATOR-ROBOT INTERACTION

OPERATIONAL VALIDATION

DANIEL W. SMITH JR.

COMBAT SYSTEMS TEST ACTIVITY
ABERDEEN PROVING GROUND, MD 21005

Combat Systems Test Activity (CSTA) is one of nine test facilities under the U. S. Army Test and Evaluation Command (TECOM). CSTA is widely considered as the premier standardized automotive test facility in the world and maintains a vast array of assets on 80,000 acres to test most military commodities from boots to robots.

In 1989, Combat Systems Test Activity (CSTA) was designated by TECOM as the Army Center for Unmanned Ground Vehicle (UGV) testing. In 1991, programs in support of robotics test missions at CSTA were endorsed by the Multi-Service Test Investments Review Committee (MISTIRC). MISTIRC is a body of multi-service members responsible for monitoring and reducing duplicity in testing facilities and instrumentation among the Army, Air Force, Navy and Marines. Endorsement by this group, in effect, establishes CSTA as the Department of Defense Center for UGV testing.

CSTA has undertaken an aggressive program to identify and fulfill the technical testing needs of UGV technical base researchers and developers. Short term solutions included supplementing and upgrading existing facilities, instrumentation and methodologies. Long term continuing investments include:

a. Outdoor UGV Test Area

b. Indoor UGV Test Area

c. Standardized Navigation Courses

d. Sensor Test Ranges

e. Leverage and upgrading of existing assets

e. Automated Data Acquisition System (ADACS)

Technical testing attempts to measure and baseline, under repeatable conditions, the engineering performance characteristics of a system. Although extensive research has been conducted on UGVs, the technical data is scarce and scattered among various government and industry organizations. In addition, this data was collected using varying and generally undocumented procedures.

The CSTA Detailed Test Plan for the Technical Feasibility Test of the Surrogate Teleoperated Vehicle (STV), approved by the Project Manager for UGVs is a barometer of our current test expertise and capabilities in the UGV technical test arena. Major areas of concentration include: Safety Assessment, Platform Performance, Navigation Accuracy, Software Assessment, Sensor Performance, Man Machine Interface Assessment, System Performance, Reliability and Durability, Automated Data Collection System (ADACS), and a State-of-the-Art Performance Data Recording System.

CSTA is striving to standardize the technical testing of UGVs by:

a. Promoting the concept and advantages of an international caliber UGV test center at CSTA and leveraging existing and future resources towards this end.

b. Authoring Test Operating Procedures (TOPs) concerning all aspects of UGV technical testing.

c. Developing facilities, instrumentation and expertise to support the TOPs.

d. Maintaining a centralized data repository of UGV technical test results.

Documented technical testing will play a pivotal role in UGV programs by minimizing duplication, validating the technical approach, reducing cost and risk, increasing reliability and supporting major milestone decisions.

POSITION SUMMARY

MAJOR PETER L. WEILAND

U.S. Army Training and Doctrine Command, Artificial Intelligence Center
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I am Major Peter L. Weiland, the robotics officer within the U.S. Army Training and Doctrine Commands' (TRADOC) Artificial Intelligence (AI) Center. The mission of TRADOC is *To Prepare the Army for War* and to serve as T*he Architect for the Future*. It is within this role that TRADOC acts as the principal combat developer and represents the soldier (user) in the materiel acquisition process. TRADOC generates the user requirements that initiates the research, development and acquisition materiel solutions; we are the customers. In this paper, we will present some observations concerning the user's current view toward the use of robotic technologies and some possible strategies for improving his receptiveness of the technology. Additionally, we will outline a TRADOC initiative designed to foster the growth of robotics in the Army. Our basic premise is that the user does not want robotics for purely robotics sake but will readily accept the technology where it is clearly and demonstrably beneficial. Therefore, it is desirable to increase the interaction and understanding between the developer and user communities to produce a robotic system which satisfies a user need.

Combat leaders do not have a requirement for something specifically "robotic". They do have the requirement to move, shoot and communicate. Leaders face the challenge of achieving a decisive victory and winning the war quickly with limited loss of life and resources. And now, they must accomplish this in an environment of reduced financial and personnel assets. Robotic systems have the potential to substantively increase his ability to accomplish these tasks. If a system is developed within the context of the user's operational scheme, the user will support a robotic system. This point is frequently overlooked by the laboratories which sometimes develop systems based solely on functionality and then search for an operational need. A problem that has impeded the proliferation of both robotics and AI systems is that they are often initially only partial solutions that go looking for deficiencies. This approach is not only inefficient but it also results in systems that often do not meet all user needs and will subsequently lack the necessary proponent support. It is vitally important to consider these proponency and institutional issues as they will ultimately decide the fate of military robotics. Systems that fail to develop strong user support are not resourced in prioritization efforts. To avoid these pratfalls it is essential to develop robotic technologies within the context of the user's operational vision.

Both the user and combat developer communities recognize the military potential of robotics. They have little reason not to believe that robotics will someday proliferate, and may even dominate the battlefield (whether this belief comes from a thorough understanding of the technology or through the popular media is debatable). However, while users recognize that robotics represents the future, they are slow to pursue the technology for two reasons which may be factually or perceptually based. First, they do not think the technology is mature enough to provide any immediate, significant or substantive enhancement to military operations. Prior demonstrations have not displayed

a performance level or utility to justify a greater commitment of resources. Previous overselling of the technology has resulted in unfulfilled expectations. Second, the user perceives robotic systems as being too costly. His perception is based not only on initial research and development costs but also with follow-on procurement and maintenance costs. This reluctance for pursuing robotics is further exacerbated by the current funding environment.

With the end of the cold war, it is inevitable that all NATO parties will face increasing challenges to their defense budgets. This presents both a challenge and an opportunity to the field of military robotics. The challenge is an extremely difficult environment for initiating or justifying a new system. Competition is increasing for available funds and a robotic system may be at a distinct disadvantage when facing systems supported by established priorities. Conversely, defense cutbacks create an opportunity for robotic systems which enhance military effectiveness at a reduced life cycle cost. Robotic systems are potentially money savers which may even free-up both financial and personnel resources for other, more traditional military tasks. If robotics can demonstrate a significant reduction in operational costs, their acceptance and utilization will obviously increase.

A 1987 National Research Council Study on Robotics and AI concluded that 'a general lack of technological understanding and a lack of a champion are the two major impediments hindering the integration of robotic technologies within the U.S. Army.' These conditions prevail today. The lack of robotic knowledge in the user community perpetuates the sentiments of robotics being *not ready* or *too expensive*. Without demonstrated utility, senior leaders are hesitant to provide support. These conditions prompted the development of a TRADOC initiative designed to educate the user community, establish relationships between user and developer, and generate requirements which will exploit robotic capabilities to the benefit of the user. From here, a champion will emerge when the technology matches expectations.

Approximately one year ago an effort began at TRADOC Headquarters to encourage the evaluation and utilization of robotics in military hardware. This multi-faceted effort is designed to educate the user community, determine potential areas of application, establish priorities for pursuing particular technologies and establish an Army commitment to the technology. The basis for this effort is the belief that we are under-utilizing the technology and that robotics possess the potential to accomplish numerous military missions at either a reduced operating and sustainment cost or in a more efficient manner. A study is currently underway to evaluate robotic concepts in a myriad of applications. This study will analyze both separate robotic systems and robotic components to major systems. This second category, robotic components, offer a very lucrative means of incorporating the technology in fielded systems. From this study we will encourage proponent agencies to assess and, if applicable, pursue a robotic solution. In the interim, we are establishing a conduit for the transfer of both user requirements to the developing community and technological information back to the user community. This actin is designed to establish a broad base of technical understanding within the user community and enable the researcher to direct efforts at specific user requirements.

The user community understands the potential of robotics but currently perceive the technology as being to exotic. It is crucial for the robotics community to provide education and demonstrations which convey the realistic capabilities of robotics. It is also important for researchers to pursue applications within the context of the users operational scheme. The current funding environment offers an unique opportunity for robotics. Users are looking for ways to reduce cost and enhance military effectiveness.

The intrinsic characteristics of robotics makes them a viable candidate for this purpose. While there are few robotic systems currently under development, there are a myriad of potential applications that may significantly alter the conduct of military operations. For our services to reap these benefits, the developer and user must work together and develop mutually supportive doctrine and technology. If we wish to maintain our technological edge over our potential adversaries and reap the benefits of robotics, we must focus our efforts on producing viable and desirable robotic systems.

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SUBGROUP 2

PLANNING, NAVIGATION AND FUNCTION ALLOCATION

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Summary of Position

Jan LEYSEN
Royal Military Academy
Brussels (BELGIUM)

A first category of robotic systems to be used by the military are not different from these used by the non military. It essentially concerns the use of programmable machinery (NC machines, assembly robots, visual inspection of production,...) in production environments.

The second category of applications is specific to the military. It seems that military applications dealt with by robotic systems will be primarily characterised by hazardous circumstances : (removing) mines, reconnaissance, etc.

It is very important that the interface between operator and robotic system becomes user friendly. This means that the objective/task to be executed by the system can be stated at a high level and in a manner naturally related to the task at hand.

These constraints have several implications. First, the system must be able to translate the natural high level description of the task into a form that is understandable and executable by the part of the system responsible for the task execution). Secondly, the type of tasks that are under consideration are characterised by an essentially non deterministic and complex environment and circumstances. A system that deals with such environments must be capable of exhibiting `intelligent behaviour' : observe the environment, interpret these observations and deduce in the new context the actions necessary to further progress towards the objective. For this reason, the further development and application of techniques originated in the AI domain is mandatory for the successful application of autonomous robotic systems in military environments. However these techniques must be combined with traditional and essentially numeric methods that are used for controlling robotic systems.

I would like to illustrate the previous considerations by summarising some of the directions and results of my research efforts. This research is situated in the area of robotic assembly and is directed towards automating the programming/execution process of assembly. The present result of this work is a system capable of generating a force controlled robot program to assemble one a part with the rest of the assembly. The assembly problem is defined in a graphical thus natural and high level manner, by bringing the part to assemble on a computer screen consecutively in the initial and the desired position. The system then transforms this graphical problem description into a numerical form. An algorithmic and numerical method is then used to synthesise a first idea of the solution, also expressed in a geometrical/numerical way. This description is then transformed into higher level descriptions composed of both symbolic and numerical elements. A reasoning mechanism based on heuristic rules is then used to gradually build up a robot program that realises the assembly. This program also contains a high level description of how the (force and velocity) sensory information may be expected to vary during a normal execution of the assembly. These descriptions can then be used during the task execution to monitor the assembly execution at a high level.

It is clear that the here described system could be integrated in an automatic ammunition loading system.

The system uses several types of problem representations (graphical, numerical, symbolic, qualitative) as well as different problem solving methods (numerical/algorithmic, symbolic/heuristic). This hybrid architecture as well on the level of problem representation, as on the problem solving level, seems an essential characteristic of future military robotic systems that will operate in very unstructured environments.

2

KEY PERSONNEL

NAME Jan LEYSEN

BIRTHDAY April 22, 1959

NATIONALITY Belgian

POSITION Lecturer in Applied Mathematics in the Department for Mathematics and Informatics of the Royal Military Academy (BRUSSELS) (since 1987)

EDUCATION BSc Civil Engineer in Telecommunications

BSc Civil Engineer in Construction

Royal Military Academy

Polytechnic Division

1982

PhD Applied Science

Katholieke Universiteit Leuven

1991

PREVIOUS POSITION

1983-1986

Commander of a Logistic Unit in Germany (SPICH)

1986-1987

Assistant in the Department for Mathematics and Informatics of the Royal Military Academy (BRUSSELS)

SCIENTIFIC PRICES

AIA Price for his BSc dissertation (1983)

PROFESSIONAL SOCIETIES

IEEE - ACM - KVIV - SOGESCI

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Workshop on Critical ORI Issues
NATO RSG-18

Participant:

Robert Chesney
Advanced Guidance Concepts Group
Defence Research Establishment Suffield
Box 4000
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CANADA

Background:

Primary experience is in control systems for unmanned air vehicles (UAVs) used in surveillance roles; including air vehicle control, payload control and mission planning. Current research areas include: system design issues in mission planning and control systems for unmanned vehicles; development of mission planning methods that embody operationally relevant task elements; and methods to integrate local obstacle maps into goal oriented path planning for unmanned ground vehicles.

Comments on Critical Issues and State of the Art in Areas Related to Planning, Navigation and Task Allocation:

The key issue in these areas is a requirement for the operator to be able to control the robotic system in terms of tasks or functions that have operational significance. The operation of typical robotic systems is divided into the concurrent (or consecutive) operation of independent subsystems within the robotic vehicle or system. This requires specialized training and an intimate understanding of the operation of all of the subsystems and potential interactions between systems. This tends to result in a system that is too operator intensive for effective use in most military roles; although potentially still very useful in conducting occasional operations in extremely hazardous environments.

It is possible for robotic systems to embody a very large collection of degrees of freedom in operation, especially in regard to systems with mobile platforms and multiple interacting payloads. The operator interaction with these systems has to be defined in a manner which suppresses the requirement for the operator to manage and control independent actions and allows him to specify "system" actions in a goal or task oriented manner.

An illustrative example can be drawn from surveillance UAVs. To the operator a UAV task is to obtain specific information about a designated search area, typically the extent, location and disposition of any enemy forces that may be in the area. To accomplish this the operator, or the UAV system, must control 4 degrees of freedom in control of the vehicle (roll, pitch, yaw and thrust), three degrees of freedom associated with the imaging payload (pan, tilt and zoom), and interpret the imagery. A simple teleoperated system would force the operator to control all of these functions independently while interpreting the imagery. A more sophisticated system would allow him to designate a point on the ground with the payload and air vehicle position being managed to maintain that point in the field of view. A task oriented implementation would allow the search area and resolution requirement to be specified and would have the system methodically image subsections of the search area at adequate resolution to

locate targets. A truly task oriented robotic system would accept as a task the definition of the search area and return information about threat forces in the area.

Identification of system functions that implement operationally relevant tasks, or that can be aggregated to perform operationally relevant tasks and operator interaction methods to allow the operator to rapidly specify the functions are critical steps in allowing effective use of robotic systems. Once these goals are defined, the development control strategies to implement these functions can then proceed within technological limits.

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Relevant work carried out at the Army Personnel Research Establishment (APRE).

APRE has been researching human factors issues of remotely piloted flying vehicles (RPVs) for at least ten years. We use a simulation of an RPV system as a tool to discover potential problems in advance of system design. We then evaluate potential solutions which can become embodied within the design of the system. Our work has covered such issues as task allocation between crew; task design; workstation design; control of multiple air vehicles; design of a deployment planning workstation for an RPV troop commander, and performance of ground control station crew in stressful conditions such as when crew are fatigued.

Our work on the above has provided a substantial input into the design of an RPV system which is currently undergoing customer acceptance testing; as well as providing an estimate of crew performance. We are also overseeing the human factors issues arising during these tests.

Meanwhile, our laboratory work continues. Now that the design specification and crew performance have been addressed, we have turned our attention to the concepts of operations and further evolution of the mission controller's workstation.

Important unresolved issues.

Two issues are uppermost in our work this year: how much of the mission planning and control to automate; and how to enhance the intelligence gathering capabilities of the RPV system.

I see the above issues as being particularly important from the human factors point of view. Technology has evolved such that we are in a position to choose what to automate. Our knowledge of human performance has evolved such that we know the types of tasks that people can perform well, and those which they perform less well. If we over-automate, then we are in danger of reducing the operator's task to one that he is likely to perform less well. We also need to ensure that he has sufficient information (not too much,) to keep him informed of system performance, thus enabling him to take the most appropriate action in the case of partial system failure.

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SG-2: Planning, Navigation and Task Allocation

Edwin R. Smootz
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The United States Army has been continuously involved with unmanned aerial vehicles (UAV's) since it began development of the Aquila system in 1974. Development of that system was stopped in 1988, and the Army's focus is now on testing and evaluating "off- the-shelf" candidates for a short range (< 300 km) system. Our past experience with UAV systems has revealed a number of concerns with operating such systems. Some of these concerns have been resolved, but others continue to appear in the systems on the market today. Several of these concerns are relevant to Subgroup 2.

Mission Planning: This area has been an issue for some time. While testing and evaluating Aquila, it was found that system commanders accepted many missions from higher headquarters which could not possibly be accomplished. Either the operational capability of the UAV system was not adequate (e.g., insufficient resolution to see targets) or the mission was too large for the time allowed. UAV system commanders are typically young soldiers who are eager to please, and consequently they are prone to accept even missions that they suspect they cannot accomplish. In some cases, depending on their training and past experience, they might not even recognize that a given mission is impossible to accomplish. In any case, building checks into the planning process to help system commanders evaluate whether or not they can accomplish the mission they have been given is crucial to avoiding this problem. In addition, and just as important, mission planning and validation must be capable of being done rapidly in order to be responsive to a dynamic battlefield. Furthermore, it must allow for ongoing missions to be rapidly revised. This requires a combination of software aids in the mission planning facility and specialized skills on the part of the operator and commander. Mission planning and validation is currently a slow and tedious process. It is a topic that continues to be of great concern to us.

Navigation: Navigation is an extremely important ORI issue for inexpensive, very close range systems. The more expensive, longer range systems possess automated aids that take the burden of navigation from the operator. The shorter range UAV's, however, rely more on direct operator control, and developing a means to keep the operator oriented with respect to his aerial vehicle is an important problem. The development of interfaces

that are usable by a typical soldier of average, or even below average, mental capability is important.

Functional Allocation: Allocation of function between operator and machine is a major issue in a number of areas. Launch and recovery is one example. A pilot can be used to launch and recover a UAV on a runway, or a launch and recovery subsystem can be employed involving, for example, a rail for launching and a net for recovery. While launching and recovering a vehicle from a runway has advantages in terms of not needing a launch and recovery subsystem, there is a cost in the additional personnel training and skills required. This is particularly true with respect to launching and recovering under a variety of environmental conditions. It is still uncertain which procedure is best. Mishaps can and do occur with both approaches. Another allocation of function area focuses on flight operations. How much information does an air vehicle operator need about how the vehicle is flying? What feedback does he need about the vehicle itself (e.g. fuel usage rate), the environment, and the mission in order to adequately control the vehicle in an emergency or if there is a sudden change of mission. This issue becomes even more important when there are two or more vehicles being controlled by a single operator, as when one vehicle is serving as the data link relay to another vehicle.

Other Issues: Finally, there are a number of important issues that pertain to the concerns of some of the other subgroups of RSG-18. The most important one is target acquisition. The ability to reliably detect and identify targets in a reasonable time remains an issue of great concern. Whatever the advantages of having a bird's-eye view of the battlefield, the UAV mission payload operator is still looking at the world through a straw and is seeing it from a perspective to which he or she is not normally accustomed. The problem is compounded by the need for operators to simultaneously engage in various procedures, such as manipulating camera controls, in order to acquire targets and keep them in full field of view. Low rate of target detection and identification continues to be one of the major issues that must be addressed in our development of UAV's.

Another issue that is important concerns the hand-off process between launch-recovery operators and air vehicle operators during launch and recovery operations. Good communications and interpersonal coordination are essential in order to safely launch and recover UAV's. But because of the coordination required, this process has more potential for mishap than other processes during a UAV mission. Consequently, this is an area which also must be looked at closely.

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Telerobotic Systems Section
Robotics & Process Systems Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee, USA

Main Areas of Research Interest

Over the past 15 years, ORNL has been involved in robotics and remote systems technology in various applications which generally involve high nuclear radiation. In the past 5 years, this experience has also been applied to other hazardous environments such as space and military applications. Most recently, the focus of this work has been on environmental restoration and waste management in the clean-up of the US- DOE complex. The focus of the Telerobotic Systems Section is on the electronics, controls, and systems engineering of robots involving sensing, mobility, manipulation, and human- machine interfacing in unstructured and hazardous environments applications. Our work has covered the full spectrum from teleoperation through autonomous systems. This work has also involved both basic and applied research in these areas. Three autonomous robot platforms have been developed for basic research in navigation and path planning, combined mobility and manipulation studies, and cooperative robot interaction research. Several prototype force-reflecting telerobotic systems have been developed with the most recent being the NASA Laboratory Telerobotic Manipulator which explored innovations in modularization, distributed electronics, traction drives, and redundant kinematics.

Overall, my research interests are very broad. I am particularly interested in the conceptual definition and implementation of practical robot systems which integrate mobility and manipulation in work task execution. More specifically, I am interested in critical actuator and control technology issues. With our focus on man-in-the- loop systems, I also have a very keen interest in many dimensions of human factors as they relate to human-intelligent machine interfacing.

Operator-Robot Interaction State of the Art

There appear to be two classes of operator/robot interaction as evidenced in human-robot interface implementations.

•First, there is the general class of operations and programming interfaces provided with commercial robot systems. These interfaces are implemented using conventional combinations of hard wired buttons/indicators, simple alphanumeric CRT displays, and keyboards. The emphasis on these interfaces is programming and diagnostics.

•Second, there is a "universe" of interface systems developed for various prototype and research systems. The variations, both hardware and software, are much greater in this class. All most every imaginable combination of "keyboards and tubes" has been tried with a great deal of variation in terms of human factors forethought. In the area of manipulation, there are several different types of master controllers under development from six-axis force balls to innovative actively-driven six-axis controllers.

There do not appear to be good examples of comprehensive development of the entire human-machine interface from a requirements-driven perspective including systematic tradeoff evaluation of key technology options. Work done with major military weapons systems may have extensive human factors experimental evaluations, but usually involving out-dated technology. For example, today's color graphics technologies offer incredible

options for the use of windows, 3D iconic and data representations, 24-bit color palettes, translucence, high-resolutions, etc. The range of options in this almost routine visual implementation media is overpowering.

We do not have a systematic synthesis process whereby one can take specific robot system task requirements and then "design" to performance criteria in the manner of routine engineering design. These systems are being built, for the most part, around opinions and personal preferences. The design space for operator-robot interaction also extends into the other sensor modalities such as audio feedback, oral communications, tactile and kinesthetic feedback. The lack of design methodology exists in all of these modalities.

Another key area of deficiency exists with regard to the integration of human control into hierarchical robot systems. Systems such as the NASA Flight Telerobotic Servicer, which has now been canceled, are conceived with an emphasis on supervisory and/or autonomous control, with manual control and human intervention as an afterthought. The effective integration of human interaction in multi- layer hierarchical control systems is not well understood. This includes real-time role definition and task allocation.

Operator-Robot Interaction Critical Issues

The critical issues pertaining to operator-robot interaction center around the general lack of systematic design methodologies and efficient tradeoff evaluation methodologies. Human factors practices seem to be more oriented toward the explicit evaluation of specific designs rather than the development of synthesis techniques which allow engineering designers to integrate human factors constraints into the design process. This opinion applies to both hardware and software design issues pertaining to operator-robot interaction. Today's technologies are advancing at a rate which far outstrips our ability to understand how to use them effectively. Somehow we must develop more effective robot design practices which allow us to incorporate more realistic human factors considerations into the evaluation of technology tradeoffs.

In the context of Planning, Navigation, and Task Allocation, the subgroup will come prepared to discuss the following critical issue areas:

(1) integration of human control and intervention across real- time hierarchical systems,

(2) robot design methodologies which integrate human factors,

(3) humanly-interactive dynamic task allocation based on performance criteria,

(4) manipulation task planning involving multiple arms, tools, and parts/materials handling, and

(5) technology driven interface development and design.

SUBGROUP 3

VEHICLE MAN-MACHINE INTERFACE

(HIGH BANDWIDTH PLATFORMS)

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3

Position Paper on Issues in Operator/Robot Interaction (ORI)

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Excerpt from stated Objectives of Workshop:

> "Unmanned vehicle systems have been developed for a variety of uses. Each of them, in one way or another, is controlled or supervised by a human operator...."

A number of important tradeoffs are brought to light in the above excerpt. In one sense, the term "unmanned systems" in the first sentence inherently encompasses the implication that such systems are intended to be operated *autonomously*. The sentence following negates that suggestion, however, by reinforcing the belief that some role for the human operator will remain, and be instrumental for the successful operation of such systems. Even though the intention clearly is that no humans will actually *ride* on such vehicles, they can hardly be considered "unmanned" if, in fact, they are being controlled – at a distance – by a human operator. Perhaps the term "remotely controlled" vehicle (RCV), or alternatively "remotely manned vehicle" (RMV), would be more appropriate?

A more significant aspect of the above point concerns the degree to which the human operator can in fact be allowed to operate effectively and reliably as a *supervisory* controller, rather than as a continually in-the-loop *manual* controller. Implicit in the latter option is the constraint that, if the human operator is to remain continually in the loop as a manual controller, s/he, most likely, will be limited to a one vehicle per operator basis, whereas effective supervisory control may open up the possibility of having one operator control more than one RCV at a time.

Without elaborating here on the well-known concept of Supervisory Control and its multiple modes of implementation, as proposed variously over the years by Tom Sheridan and his colleagues for example, suffice it to say that Supervisory Control can exist along a *continuum* of levels of involvement of the human operator with the control of the system. To speak of either pure manual control or strictly automatic control belies the point. Any investment in implementing automation is *supposed* to repay itself as some combination of the following benefits: reduced workload for the operator, the need (possibly) for fewer operators, improvements in control (sub)task performance, fewer control errors, reduced costs, etc. In reality, however, quite often the impetus towards more and more automation is driven principally by progress in the associated automation related technologies. The clear challenge for wisely allocating functions between human operators and machine components, and therefore one of the potentially critical issues relevant to the workshop, is to develop a reliable *model* of the human (supervisory) controller for any given ORI situation, which will be sufficient for predicting the informational needs of the operator in relation to the control task. It is these needs, not available technology, which should be used as the driving factor for determining appropriate allocation strategies and specifying automation requirements.

Another way of summarising the thoughts outlined above is that any debate on the "issue" of manual vs autonomous control will inevitably miss the point that it is towards some "optimal" *combination* of these concepts that we must strive. Current research in the Human Factors in Telerobotics Laboratory (HFTL) at the University of Toronto, for example, is centred on the development of a

taxonomy of information needs and control modes for remote teleoperation, with the ultimate aim being to specify display and control requirements for particular classes of teleoperation tasks. Whereas we recognise the advantages of intelligent automation, we also continue to emphasise the important need for retaining some role for the human operator. We reject, in other words, the notion of autonomy strictly for the sake of autonomy.

The primary objective of technological advances in Operator/Robot Interaction (ORI) must therefore be to off-load designated tasks from the human operator, where possible and appropriate. Typically these will be *low-level* tasks, which demand some degree of vigilance, precision, repetition and, generally, tedium. The operator should thereby be freed up to carry out such higher level tasks as pattern recognition, situational assessment, decision making, planning, etc.

Our own primary activity towards this end, for example, is the development of a ***hybrid virtual control*** capability, which is based upon an integrated combination of closed circuit live stereoscopic video, computer generated virtual stereographics, multi-degree of freedom controller devices, and low-level computational vision. This provides a flexible means of permitting a human operator to visualise and remotely "probe" a remotely viewed environment, an important capability for reliable situational assessment. An additional purpose is to provide the human operator with a means thereby to communicate relevant *quantitative* task-related information about the remote environment to a control computer – for the purpose of planning, programming, synthesising and visualising intended actions, which can subsequently be offloaded from the human operator and be executed under some form of machine mediated control.

It may be too optimistic to presume, however, that the introduction of such off-loading technologies will necessarily result in generalisable reductions in crew complement. Except in cases for which extended vigilance may not be necessary, such as operations which are repetitive, highly predictable and/or have very long time lags – which may or may not actually be relevant to military settings – it is doubtful whether single operator / multiple vehicle systems will be practical within the foreseeable future. That is, with the human operator acting as a critical planner, decision maker, instructor and monitor, even if not continually, it may not be feasible to control multiple vehicles.

The following is a summary of the main issues which have been touched upon here:

- Increased levels of automation will (inevitably) be introduced into the ORI, but the human operator will remain a critical system component.
- Models of human supervisory control behaviour are necessary for making function allocation decisions and for developing ORI workstations – much research is still necessary to achieve this.
- It should not be taken for granted that one operator will, in the general case, be capable of controlling the actions of multiple RCV's.
- The role of technological developments in the ORI should be to off-load the human operator from tedious tasks, and to allow him/her to concentrate on those higher level cognitive tasks in which humans excel.
- One important class of capabilities which we should be endeavouring to provide the operator is a combination of enhanced means for accurately visualising remote worlds, assessing current strategic situations, communicating quantitative information to computer controllers, planning control responses and simulating the impact of intended actions

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Dr. Borredon is head of the group that sponsors basic research on human science topics, including personnel selection, training, human factors engineering, and physiology. His group sponsors French Ministry of Defense research on human factors issues in unmanned systems.

Dr. Borredon is the French delegate to AC/243 Panel 8 on Defence Applications of the Human and Biomedical Sciences, which is the parent panel for RSG-18 on Operator-Robot Interaction.

Dr. Borredon received the Doctor of Medicine degree from the Faculty of Medicine, Lyon, in November 1962; the Doctor of Natural Sciences degree from the Faculty of Sciences, Nancy, in May 1970; and was elected a Laureate of the Academie Nationale de Mececine in 1984.

Before assuming his present position in 1986, Dr. Borredon had a distinguished career in biomedical research and research administration. He is the author of numerous scientific articles and book chapters.

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SUMMARY OF POSITION ON CRITICAL ORI ISSUES

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The following comments refer to mobile robots.

1. Even if a robot is to some extent remotely controlled, it should be capable of autonomous operation to a significant extent. This is necessary to facilitate control by the operator.

2. The robot should have some sort of survival instinct letting it refuse to obey operator commands that would cause the robot to be destroyed (for instance, by toppling over while moving in rough terrain).

3. Resolution of resulting conflicts between the operator and the robot can be difficult. If the intelligence and the abilities of the robot for sensing and for comprehending the situation are insufficient, the interaction may be frustrating for the operator.

4. Introduction of a robot into a new environment can be very difficult. Some robots require a detailed and perfectly accurate map of the area in which they are supposed to operate. Such a map is very difficult to provide, and errors in the map may lead to accidents. To overcome this problem, the robot must be able to operate while using only rough, approximate maps. Moreover, it should be able to generate such maps automatically by wandering around autonomously, or to cooperate with the operator in generating the map.

   Such abilities require a powerful and sophisticated sensing system and a high degree of machine intelligence. One approach is to provide the robot with a repertoire of behavior patterns it can execute automatically. The high-level control task is then reduced to the selection of behavior patterns in an appropriate sequence. The practicality of this approach ("behavior-based navigation") has been demonstrated using an indoor mobile robot.

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High Bandwidth Telerobotic C^2:
An Opportunity For *Serious* Virtual Reality,
Telepresence and ORI Research?

Robert J Stone
UK National Advanced Robotics Research Centre

Teleoperation is a term describing the extension of a person's sensing and manipulation capability to a remote location and teleoperator, but can also be used generally to encompass *telerobotics*. *Telepresence* is the ideal of sensing sufficient information about the teleoperator and task environment, and communicating this to the human operator in a sufficiently natural way, that the operator feels physically present at the remote site (Sheridan 1987, 1989).

This short paper is generally concerned with the use virtual reality technologies for achieving "intuitive" MMIs for teleoperation, telepresence and telerobotics. An intuitive interface between man and machine may be defined as one which requires little training (particularly in complex operational procedures or computing languages) and proffers a working style most like that used by the human being to interact with environments and objects in his day-to-day life. In other words, the human interacts with elements of his task by looking, holding, manipulating, speaking, listening, and moving, using as many of his natural *skills* as are appropriate, or can reasonably be expected to be applied to a task.

However, does "intuitive" imply that remote handling and inspection will only be achieved successfully and safely if the robot and MMI systems are so closely matched that every sensory and motor feature of the human is duplicated in the physical make-up of the robot (ie. anthropomorphism?). The answer to this is no. Anthropomorphic man-machine systems, such as the American Naval Ocean Systems Center's *Green Man* Exoskeleton-Slave Project and the MMIs which appear to dominate the Japanese approach to teleoperation have met with varying degrees of success. The reason for this (particularly in the case of Japanese research) is a lack of attention to what information and control facilities the operator actually needs to complete a specific task. Some tasks (eg. inspection of large, cluttered areas) may be well suited to using head-mounted displays, others (eg. fixed area inspection) may only require conventional 2D camera and display devices. Some tasks may well benefit from using glove interactive devices, others may not demand such complexity. The diversity of tasks faced by the military demand attention to both the requirements of the task and the information processing and control requirements of the human operator.

Why should the designers of telerobotic systems even consider R&D Programmes which move towards the intuitive interface? In the first instance, there is the issue of equipment, task or facility design. Many of the installations and tasks in place today were originally designed with **human intervention** in mind. This means two things. Firstly, a single, so-called advanced telerobot, capable of limited learning and extrapolation by means of artificial intelligence (knowledge-based systems, neural networks, etc.), would not, by present day standards, be capable of effectively carrying out a remote task autonomously. This situation is not set to change for the foreseeable future - **the human still has an indispensable rôle to play** as supervisor (for those remote

systems with some onboard intelligence) and as a direct controller - the "manual intervener" (ie. when remote failure occurs, or when the situation facing the robot is outside its scope of "competence"). The transition from supervisory control of a telerobot to telepresence in the case of systems failure or uncertainty was not addressed adequately in Sheridan's definitions. Secondly, the deployment of a primitive robot platform (vehicle and/or manipulator) currently places undue mental and physical workload on the remote human operator, since the designer - consciously or unconsciously - appears to expect the human to adapt to working remotely with the most inappropriate man-machine interface facilities possible (eg. batteries of joysticks and complex multi-screen displays). Of course, humans eventually adapt very well to most man-machine interfaces. Driving a car is an example here. Nevertheless, adaptation (or training) takes time and money, and does not guarantee constant efficient and safe performance. Under conditions of fatigue and stress, even the most proficient human operator can, in a split second, misinterpret a display or control condition, or revert to a previously dominant stereotype, with possibly fatal circumstances.

Secondly. a related and (unfortunately) unavoidable issue is that of operational cost. Existing MMIs for teleoperated systems do little to save money for those who have commissioned their use. Why? Again the reason is a human factors one. By paying lip service to the actual nature of human perceptual and motor characteristics, and their integration, the MMIs "bolted-on" to a remote system at the last minute require *substantial training programmes, are inefficient operationally* (for the reasons given above), could be inherently unsafe (due to the stereotype issue also listed above) and are likely not to be accepted by the "hard-line" operator in the first place. Equipment developers are often to blame for these problems. A costly stereo television system or multi-axis controller might sound an attractive proposition when the experimental results show an *n%* improvement in performance under controlled conditions, but when this percentage relates to an advantage of just tens of seconds in the real world, one must question the expense of the initial outlay.

There is no doubt in the author's mind that a "natural" or intuitive MMI will result in operational savings. But this will only occur when the designers of MMI equipment recognise that the human sensory and motor factors are integrated and that specific attention to human stereo vision, *or* eye movements, *or* head movement, *or* tactile feedback, *or* force feedback, *or* 6-degree-of-freedom hand/wrist control will simply not succeed. One often finds statements in reports, by establishments with a commercial background, which read something like: "...stereo vision provides superior remote handling performance over conventional viewing techniques and force feedback...". These should be treated with scepticism. These facilities should simply **not** be considered in isolation in the first place. When handling an object in the real world, vision, cognition, motor "preparation" (subconscious adaptation of the human motor system to prepare for handling a heavy or light load), tactile feedback, kinaesthesis and closed-loop muscular adaptation all play an integrated rôle in effective materials handling. This is what a programme of research into natural or intuitive MMI, for telepresence - such as that under way at the UK's Advanced Robotics Research Centre (ARRC) - must address.

Virtual Reality (VR) and associated technologies is a relatively recent development which, it seems, has given a new lease of life to those engaged in addressing the human

factors aspects of telepresence for hazardous environments. VR has, in amongst the hype and rhetoric surrounding the field, spawned a substantial industry with an almost obsessive dedication to developing and supplying low-cost and reliable "natural" MMIs. With the number of VR proposals evident in the recent call for ESPRIT III involvement, this trend is likely to continue for the foreseeable future, leading to a dearth of devices, only some of which will be useable by those involved in robotics and teleoperation developments.

The ARRC's Virtual Reality (VR) and Telepresence experimental test bed has been used to evaluate the interaction between human operators and semi-autonomous mobile and manipulative robots. Equipped with head-mounted stereoscopic displays and intuitive input devices, such as gloves, 3D "mice", speech recognition and synthesis, operators are tested controlling either a robot vehicle (Cybermotion K2A) and/or an enhanced Puma Robot Arm using the Company's singularity-free controller. Virtual models of architectural and hazardous environments are constructed using a range of VR toolkits, although the Centre has recently demonstrated the feasibility of converting objects and surfaces, derived using a scanning laser rangefinding system, into 3D virtual images, suitable for display on a stereo headset. This will improve the performance and safety aspects of deploying future robots into environments where conventional TV feedback to a human is inadequate (due to smoke, fire, turbid water, etc.), except at close range. For close-in task performance, the ARRC has also developed a head-slaved stereoscopic camera system, capable of pan/tilt carriage speeds of the order of 1800°/sec. In order to permit the switching between, or merging of VR imagery and real video, the Centre uses a multi-transputer/i860 engine to coordinate these and other real-time aspects of the test bed. The Company has also pioneered the use of tactile feedback for VR and telepresence applications, in both glove and 3D "mouse" form. The Company's Teletact™ Glove is now being marketed by VPL Inc. of Redwood City, CA. Complex virtual models have been built and demonstrated, including a model of the Robotics Centre, complete with an animated Puma Robot, which can be driven from a control panel and can demonstrate "teach-and-repeat" behaviour. The ARRC specialises in the porting of models from CAD-like systems onto more dynamic platforms supporting VR, thereby permitting "immersion" and intuitive interaction on the part of the human operator.

Other Military Telepresence Issues (Related Topics/Applications)

Urban area clearance (scaled-down version of NOSC's HMMWV or UK SAFFAR (Security & Fire Fighting Advanced Robot), robotic patrol, surveillance and intruder intercept,

Mine clearance/disposal (Urban/Large Area - SAFFAR and Subsea from MCMV),

Submersible Deployment From Conventional Submarine (deep water mine clearance?),

Infantryman 2000 (special forces equipment - telepresence rôle; remote weapons control?),

Tactical Supervisory Control of Battlefield Robots (God's Eye View) and C^3I,

Offshore Platform Submersible Patrol,

Subsea Salvage and Emergency Submarine Location.

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Summary of Opinion
for
RSG-18 on Operator-Robot Interaction
SG-3 High Bandwidth Platforms

Attendee: Bruce E. Brendle Jr.

Organization: US Army Tank-Automotive Command
Robotics Office (AMSTA-ZR)
Detroit Arsenal, MI 48397-5000

Opinion of the State-of-the-Art
(The following comments are limited to efforts that TACOM participated in)

The Tank-Automotive Robotics recently completed several efforts that have advanced the state-of-the-art in Operator-Robot Interaction (ORI) for Unmanned Ground Vehicles (UGVs). These efforts are the Robotic Command Center (RCC), Enhanced Computer Aided Remote Driving (CARD), a Control Unit Interface (CUI), and two Video Compression techniques In addition, TACOM has developed a set of Common Communication Protocols (CCP) that allow communications interoperability between UGV testbeds.

The Robotic Command Center represents a unique asset to the UGV community, and its completion represents the culmination of five years of development. The RCC is a mobile testbed mounted on a Roland XM975 chassis, for development, integration, and testing of technologies for single and multiple vehicle control of UGVs. Using digital terrain data base products, automated destination selection and route planning, Computer Aided Remote Driving, and Autonomous Road Following, the testbed allows two drivers and one commander the capability to simultaneously control four UGVs. During acceptance testing of the RCC in October, 1991, robotic functions demonstrated for the first time ever include control of multiple UGVs by a single operator, hand-off of control of a UGV between operator stations, and control of a UGV from a moving control unit. The tested is flexible and extensible, facilitating the integration of technologies from diverse sources.

The Common Communication Protocols serve as a first step toward UGV testbed communication interoperability. Two testbeds sharing compatible communication hardware and implementing CCP are directly interoperable. This has been successfully demonstrated using the RCC. The RCC is the first control station implementing the protocols. UGVs developed by the Laboratory Command have recently been upgraded to utilize the protocols. Interoperability between the RCC and UGVs will be demonstrated in April, 1992. International interoperability is also possible through implementation of the CCP. The United Kingdom has adopted and implemented the protocols in their UGV program, MARDI. A joint US/UK interoperability demonstration is planned for late 1992.

TACOM has enhanced the Computer Aided Remote Driving used in the RCC. The new

CARD uses a Silicon Graphics workstation to provide improved ORI, as well as incorporated video compression to allow transmission of the stereo images over a 16 kbps military radio. This is the first UGV driving mode ever demonstrated over a military radio. The improved ORI includes the superposition of a three-dimensional vehicle icon inside of the stereo image, drawing a three-dimensional path for the vehicle to traverse, and then moving the icon along the path as the actual vehicle traverse the path. Passive stereo vision provides obstacle detection and avoidance to extend CARD paths.

The Robotics Office is developing an upgrade to the RCC ORI entitle Control Unit Interface (CUI). The objective of this effort is to using video windowing technology to incorporate all of the functionality of the three large video displays and touch panels of a RCC station on a single, larger, touch-sensitive monitor. Stereo video would still be possible in this configuration. The windowing hardware has been developed and tested to achieve the CUI. CUI technology will allow RCC functionality in a tremendously smaller area.

TACOM will in the short future complete two video compression research contracts. These efforts as well as those at the Massachusetts Institute of Technology (MIT) and Oakridge National Laboratory (ORNL) show promise in eventually providing a live driving video over a military non-line of sight radio link.

Opinion of Critical Issues

The most critical issue concerning Operator-Robot Interaction is the lack of experimental data to identify critical technologies for ORI. Without this data, UGV programs continue to move in diverse, and often opposing directions. Specific issues that need to be experimentally resolved include:

- Value of stereo video
- Value of peripheral videos
- Color versus black and white video
- Required frame rate and resolution of video
- Remote video Field of View
- Value of image stabilization
- Value of head slaved video
- Value of force feedback to the operator
- Importance of automotive type interface ie. wheel and pedals versus joystick
- Limited visibility operations (night, fog, smoke, etc.)
- Touch panels versus touch sensitive monitors

Without conclusive experimental data concerning these and related issues UGV programs will continue to evolve in diverse directions, resulting in additional costs and potential incompatibilities. For example, a size and power requirement for color videos currently restrains the size and weight of control units. Conclusive test results negating the importance of color would allow OCU developers to make dramatic size reductions, as well as spending development funds in different areas.

3

DEPARTMENT OF THE ARMY
UNITED STATES ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA 35898-5000

REPLY TO
ATTENTION OF

AMCPM-UG 29 May 92

MEMORANDUM FOR Dr. David C. Hodge,US Army Human Engineering Laboratory Command, ATTN: SLCHE-CS, Aberdeen Proving Grounds, MD 21005

SUBJECT: Written Summary of Position

1. Personal introduction. My name is Dr. James W. Dees. I am the human factors and test engineer for the Unmanned Ground Vehicle Joint Project Office of the United States Army Missile Command. The word "joint" in the title refers to the fact that this is both a U. S. Army and a U. S. Marine Corps project office.

2. Main area of interest/research. At this point in the project life cycle, I am primarily interested in the human factors research necessary to write a comprehensive request for proposal. These research issues generally fall in the following areas:

a. Waypoint control at varying video transmission rates from 30 frames per second to 1/6 frame per second.

b. The slaving of the driving camera is an issue with several subissues.

1. Head slaving vs. manual slaving vs. slaving to the front wheels of the vehicle.

2. Head mounted vs. pedestal mounted displays.

3. Field of view (As the field of view increases, the need to turn the camera diminishes).

4. The use of a center guide post.

5. Automatic recentering.

c. The optimum work/rest cycle with partially automated unmanned ground vehicles deployed in multiple stationary monitoring positions.

d. The best driving controllers for a combination of direct and waypoint teleoperated driving.

e. The optimization of a gravity referenced camera system relative to damping requirements and the control override system for pitch.

3. Opinion of the state of the art. All scientific/engineering disciplines are a mixture of information and techniques for obtaining information. We like to believe that with the passage of time, the application of our information gathering techniques will increase our information until ultimately we will know everything there is to know. This theoretical limit to the production of knowledge is probably not achievable in any field, but is less achievable in human factors than in most scientific/engineering fields. Human factors applications frequently include many modifying parameters that are extremely dependent on the nature of the hardware systems being defined. Therefore, whenever new ground is being broken, as in robotics and teloperation, we can draw on the human factors literature for general direction, but frequently require additional research to optimize our engineering choices. That is where we are at present in the Unmanned Ground Vehicle program.

4. Opinion of critical issues.

a. Waypoint control can not only allow a vehicle to be controlled with a minimum of visual feedback, but also transfers to the vehicle the repetitive psychomotor tasks that can easily be

automated, while retaining with the human operator the cognitive task of assigning the route and speed of travel. This should dramatically decrease the workload of the remote drive, and therefore is worthy of considerable attention.

b. When considering the control of the remote driving camera, the camera slaving issue becomes enmeshed in the scene display and field of view issues. None of these issues can be emphatically resolved without simultaneous consideration of all of them.

JAMES W. DEES, PhD
Human Factors/Test Engineer
Unmanned Ground Vehicle
Joint Project Office

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SUBGROUP 4

VEHICLE MAN-MACHINE INTERFACE

(LOW BANDWIDTH PLATFORMS)

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LOW BANDWIDTH PLATFORMS
INSTITUTION EXPERIENCE

Prof. M. Acheroy

Royal Military Academy
Signal and Image Processing Laboratory

The signal and image processing laboratory of the "Royal Military Academy" (RMA) is working in image processing since its creation seven years ago. The research activities in signal and image processing of the laboratory are concentrated in the following topics:

• Image restoration is the first research activities undertaken by the laboratory. Our department is specialized in the adaptive restoration of single images and of image sequences, it is actively working in this domain in direct collaboration with the Home office and the Ministery of Justice.
The laboratory has developed a specific deconvolution method using the Discrete cosine transform (DCT). This method allows not only an efficient deconvolution of the degraded images when the PSF (point spread function) has two symmetry axes (usually a vertical and an horizontal one, this is mostly the case for optical systems), but also an efficient adaptive noise reduction. In thermal infrared imagery, the same method is used in combination with transmission and reflection models in order to get calibrated images.

• Image compression of calibrated data is becoming a major activity of our department which is concerned with an ESA project in satellite image compression. Data compression is now essential for applications such as transmission and storage in data base and more specifically when the considered documents are satellite images. For economical and efficiency reasons indeed, it is necessary to reduce the transmission bit rate and to limit the amount of data to be stored.
Image coding with the purpose of preserving the required image calibration properties (luminance, radiance, etc.) is a more difficult task than image coding with the purpose of preserving an excellent image quality for the human vision system. Satellite image coding belongs to the first category and requires special care in order to preserve the quality of the measurements. The second category is extensively addressed in the literature and the distortion rates are related to the human vision system (HVS).
The wavelet transform (WT) combined with an adapted encoding scheme seems to be one of the most promising techniques in image compression.

• The surveillance problem in a complex environment: the goal is the construction of algorithms in the field of automatic object recognition with either a Doppler radar (one-dimensional signal) or a thermal infrared sensor (two-dimensional signal) or with the combination of this two sensors, by fusing the collected data at a high level. The methods used are as well classical pattern recognition and modeling methods as more modern methods such as the associative memories (e.g. neural networks) in combination with artificial intelligence techniques. In this last topic, the RMA is specialized in the use of blackboard models.

• Further efforts are also done in the study of the automatic face recognition problem where the developed algorithms are the result of the combination of classical and connectionist methods (neural networks).

• In the field of thermal infrared, the laboratory is also specialized in the calibration of infrared images.

NATO AC/243 (Panel 8) RSG-18 on Operator/Robot Interaction
Workshop on Critical ORI Issues
27-29 October 1992, Bordeaux, France

Abstract of Presentation (SG-4)

1. Personal introduction

Dr. Alfred Zapp
Program Manager Reconnaissance and Sensor Systems
ESG Elektronik-System-GmbH
Vogelweideplatz 9
D-8000 München 80
Tel. ++ 49 89 9216 2947; Fax ++49 89 9216 2631

Ten years of experience in research and development of autonomous and semi-autonomous Robotic Systems in natural environments.

Experimental systems: VaMoRs, ARTES.

2. Main area of interest/research

Guidance and Control of Robot Systems in rough terrain under battlefield conditions using low bandwith radio links. The operating area for the robot will be approximately 5 x 5 km^2.

- Relocation of intelligence (stepwise) from Command Center to Robot System in order to mininize communication overhead (autonomous object detection, object classification, target reconnaissance, environment evaluation using sensor mix).

- Information requirements for the operator. "Optimal ways" of processing and representation of information for operator in Command Center about actual status of Robot and its environment covered by the sensor systems in order to guarantee sucessfull completion of mission elements and to keep the Robot in a save and stable state.

- Knowledge representation (world model) in Robots data base.

- Day and night operation under all weather conditions.

- Design of MMI (modularity, standardization).

- Standardization of data protocol.

3. **Opinion of state of the art**

Problems solved in principle:

- Autonomous driving and object detection and avoidance in well structured natural terrain (Autobahn, Freeways, Country roads, to a limited extent dirt roads) under "rather good" weather conditions
- Remote driving in structured and to a certain extent unstructured natural terrain using high bandwith data links if line of sight condition
- Computer Aided Remote Driving (CARD) under restricted conditions
- Autonomous object detection and object tracking in unstructured environment
- Image data compression and coding techniques for image data transmission via low bandwith channels

Experimental results of the ARTES system will be shown (Video) and discussed in detail.

4. **Opinion of critical issues**

The central problem of GUIDANCE AND CONTROL of one ore multiple robotic vehicles is to guarantee the commandability without line of sight conditions in operating areas of app. 5x5 km^2. This requires first of all safe and reliable datalinks and secondly an appropriate man-machine interface in the Command Center.

The general requirements are that it must always be possible to send control commands from the Command Center to the Robot(s) and to receive status information from the vehicles and their environment. In case of a threat the robot must fulfill its mission and remain controllable. The operator must be able to help the robot in unexpected situations which it can not handle itself and maintain the system in a safe and stable state.

The aim can not be to develop fully autonomous systems. There will and there must always be a certain dependency of the Robot on the operator in the Command Center for interaction and control. A desirable goal would be to distribute the functions between Robot and Command Center in such a way that the data exchange is reduced to a minimum.

Up to now Robotic vehicle systems have a bandwith problem. The transmission of video images requires wide bandwith formats, but the use of wide-band systems, e.g. microwave, is limited due to the line of sight requirement. In most tactical situations, only narrow bandwith channels will be available. Therefore the main and standard datalink will be in the VHF-band allowing a net data rate of app. 9600 bit/s. This is of course not sufficient for transmitting video images.

Areas for research and development:

- Modular design and standardisation of the MMI (the operator gets what he needs)

- Visualisation of robots situation in its environment
- Organisation and lay-out of robotic data bases (world model, use of digital terrain data)
- Development of 3D-Object recognition algorithms
- Adaptation of sensor data processing algorithms on the run to changing environmental conditions
- Development of small and smart Robotic systems, simple to operate and with a minimum burden for logistics and support (modular design, of the shelf system components)

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PERSONAL INTRODUCTION:

Mr. Boumans was born in 1963 in Rotterdam, the Netherlands. During his study at the Delft University of Technology, Faculty of Aerospace Engineering, he was active in the Dutch Society of Aerospace Students "Leonardo da Vinci" and was elected president for the year 1985-1986. In 1988 he performed his graduation work on the topic of space robotics at Fokker Space and Systems, the Netherlands. By the end of 1988 he finished his Masters Thesis titled "Analysis, control design and simulation of an "insert" operation, using a three degrees-of-freedom planar manipulator model with flexible links and hinges". After graduation, he continued working for Fokker Space and Systems as a Project Engineer on the HERA project, which concerns a robot arm for external servicing of space platforms in Low Earth Orbit. Primary responsibilities include system design, real-time simulations, operations, man-machine interface design and configuration management.

Relevant Publication:
R. Boumans & C. Heemskerk, HERA: A Robot for External Servicing in Low Earth Orbits, in: Proceedings 4th International Symposium on Offshore, Robotics and Artificial Intelligence, Dec 1991, Marseille, France.

COMPANY INTRODUCTION:

Fokker Space and System (FSS) has its seat in Amsterdam, the Netherlands. It has been founded in 1968 as an independent engineering company within the Fokker consortium. Its primary markets are space and defense applications. It is currently the largest (50%) Dutch space industry, with a 1991 turnover of 67 million dollar. It has 450 employees from which approximately 40% are university graduates. In its formative period, FSS acted as prime contractor on projects as the astronomical satellite ANS launched in 1974, and participated at prime contractor level in Infra-Red Astronomical Satellite (IRAS), launched in 1983. More recently FSS has specialized in solar arrays, attitude and orbit control systems, spacecraft structures, thermal control systems, integration and test, and robotics and simulators. Specifically robotics and simulators form areas in which the design, development and production of Man-Machine Interfaces is an essential part. FSS projects in these areas serve not only the space market, but also the commercial and defense markets.

In space robotics, FSS is prime contractor for a robot arm called HERA, which is intended for external servicing of space platforms in Low Earth Orbit. FSS responsibilities in this project include preparing robot system specifications, system design, analysis and computer simulations, integration of subsystems, and system performance verification. The robot arm's behavior in space is analysed by computer simulation. This analysis is performed real- time using the purpose-built HERA Simulation Facility Pilot (HSFP). This HSFP is also an essential tool for Man-Machine Interface design and for operational analyses with an operator- in-the-loop.

The characteristics of HERA are:
- Remotely operated without direct view of the worksite
- Seven degrees-of-freedom
- Length 10 m
- Weight 200 kg
- Lift capability 2,000 kg
- Lifetime 10 years in space environment
- Operational modes:
  - Manual with handcontrollers
  - Automatic mode with supervisory control

Current FSS involvement in simulators includes:
- Sea Dragon (submarines)
- Flexim (process industry flexible simulators)
- Stinger anti-aircraft missile trainingssimulator
- Trigat MR anti-tank trainingssimulator
- Eurosim (simulation facility for training and operational procedures on-board space platforms)

OPINION ON THE STATE-OF-THE-ART:

In general, for control system design including those with an operator-in-the-loop, the two aspects determining the system control performance are the controllability and the observability. Herein, the MMI design is a critical parameter.

With controllability is meant the capability of the operator to manipulate - in a broad sense - a remotely located system. Restricting the type of systems to manipulators, three types of control can be distinguished:
a) Direct manual position/velocity control
b) Direct manual control of torques/forces
c) Supervisory control.

Direct manual control of positions or velocities by means of hand controllers is a fairly well-known technique. Many experiments have been performed and applications are already operational, e.g., underwater, in nuclear power plants or in the American Space Shuttle. Operator performance is sufficient, specifically if some form of compliance is built-in the manipulator. With HERA, many experiments have been performed using HSF-P. Some results of these experiments will be presented.

Direct manual control of torques/forces, i.e. operator provides torques/force setpoints instead of position/velocity setpoints, is a research issue. Operator performance is difficult to evaluate. For HERA, application of manual torque/force control is currently under discussion. Both hardware and software simulations with this technique are in preparation. Foreseen tools will be presented.

The supervisory control mode will be the nominal operational mode for HERA. In this mode, high level commands are given to the manipulator (MOVE TO OBJECT, APPROACH, GRAPPLE). The operator monitors the execution of the commanded operation, and intervenes if something goes wrong. The operator performance is mainly determined by his capability to intervene correctly. An overview of HERA capabilities in this area will be given.

Direct manual control and supervisory control can be considered as two extremes for operator control of a manipulator. Which control type should be chosen, should not only be determined by available technology, time or money, but also by requiring maximum use of the capabilities of the operator. In the current trend towards automation the operator tasks focus on the higher levels of the control hierarchy. Many former human operator tasks are now carried out automatically. This does not necessarily mean that the capabilities of the human operator are exploited to the maximum, specifically where it concerns safety critical or contingency operations.

The observability of a system with an operator-in-the-loop is defined here as the presentation of the information about the systems actual, commanded and/or predicted state to the operator. This information is communicated to the operator by providing stimuli to his senses vision, hearing and feeling. The implementation of the information presentation varies from simple displays to complete virtual reality environments. However, the optimal solution for a particular system to be controlled is not easy to define. One difficulty is the 3-D perception of the scene. Stereovision has turned out not always to be a solution. Grapnical aids are considered very useful to enhance operator performance. However, their use can also be limited by the available hardware. Predictive displays form a promising area of development in the area of graphical aids. The communication bandwidth between the operator and the remotely located cameras can be a technically limiting factor, specifically in real-time control environments, which require special data compression and handling techniques.

In the case of very remotely located systems, the time delays involved (for ground-to-space systems they vary between 4 seconds in Low Earth Orbit to 30 minutes to Mars) require the use of high level control techniques. For HERA, ground teleoperation is an option currently under investigation. In the design process of Man-Machine Interfaces the use of system simulation techniques is considered very important. For HERA, use is being made of HSF-P. Still a problem is the accurate real-time simulation of the complex dynamics of the space manipulator and its interaction with the environment (compliant motion), including accurate visual feedback.

CRITICAL AREAS:

The critical areas are indicated by means of questions, which are proposed to be discussed during the workshop sessions. The above may contribute to this.

The basic question is, how can we improve the MMI design process?
In more detail, the following questions should be answered:

1. How can an optimal task allocation between computer and operator be achieved, i.e. at which level the control loop should be closed?
2. How can the quality of feedback, i.e. the operator observability be optimized in order to make maximum use of his capabilities?
3. How can the issue of teleoperation under supervisory control be further exploited and made ready for use, e.g., related to time delays?

4. Is manual control of (very) flexible manipulators possible and if so, how?
5. How can force feedback be used to increase operator flexibility?

Obviously, in general the design process should be highly iterative in defining operator tasks, MMI requirements and system requirements. The potential operator capabilities are a key issue herein. Therefore, the MMI can not be considered as "just another subsystem". In the presentation, we will outline how we try to answer the above questions in the HERA MMI design process.

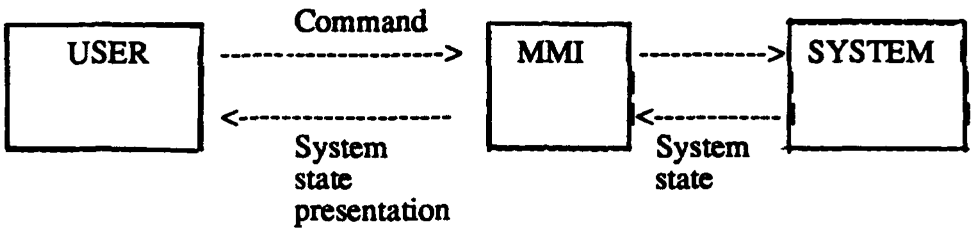

Fig. 1. Operator / MMI/ System relation

SUMMARY FOR SUBGROUP 4, LOW BANDWIDTH PLATFORMS

Ronald van Kampen
Physics and Electronics Laboratory TNO
The Hague, The Netherlands

Main area of interest:

My main area of interest in general are (semi-) autonomous systems. My main area of interest in particular is sensor data processing, computer vision, in order to build and maintain a model of the robot's environment. It is my belief that the highest level of autonomy a robot can have is limited by the information the robot possesses about its world. And the level of autonomy of a robot greatly influences the operator robot interface. I find the task of building and maintaining a world model interesting if this is done through sensors, as is usually the case with roving robots. Therefore, I prefer to use the term (semi-) autonomous systems instead of robotics, because robotics is often associated with static industrial robot arms used for welding, spray painting, etc., that operate in a well known static environment for which a world model is entered a priori, and no world model maintenance is necessary. Their sensors are typically used in low-level control loops.

Opinion of the state of the art:

Building and maintaining a world model is hard. Therefore, current research in this area often puts restrictions on the robot's world. If the world model is based on a geometric description of the environment, then the environment must be structured, because we are still inadequately able to model natural objects like trees etc. The next restriction is caused by our inability to cope with the concept of time in an efficient way. Artificial intelligence has made some progress in the area of temporal reasoning, but it still too hard to maintain a model of the world for any given moment in history. A related problem is the modelling of dynamics. It is not commonplace how to deal with speed, accelaration and followed track of moving objects in the world model. World modelling mostly merely tries to maintain a model of the current situation in a structured environment. If the environment is unstructured, only free and occupied space is managed for navigational purposes. As far as object identification is concerned, only a priori known man made objects can be identified and generic object recognition will not be possible for some time to come.

Opinion of critical issues:

As can be deducted from my opinion on the state of the art, fully autonomous intelligent robots are still a couple of decades away from us. Until then a human operator is still required. I think that the robotics community is divided in the way the robot interacts with the operator. Some people take the presence of an operator as the basis for their robotics research. They want to provide the operator as much information as possible. Ultimately, all the sense-organs of the human operator must be fed the information as if he was at the site of the robot, so the operator will truly believe he is tele-present. Also all the actions of the operator must be fed back to the robot.

Critical issues:

- A high bandwidth is required.
- It is not yet possible to simulate all inputs to the human sense-organs.
- Simulation sickness, because of small time delay
- How to represent output of sensors, that have no equivalent human sense-organ, e.g., the presence of odourless gasses, range measurements, etc.

The other approach is to strive for more autonomy. These people try to make their robotic vehicle as intelligent and autonomous as possible with the current state of technology. The robot only interacts with the operator when it is unable to solve a problem it is faced with.

Critical issues:

- Atificial intelligence still has a long way to go before it matches the reasoning, decision making and cognitive skills of human beings.

(Message # 22: 5200 bytes)
From: Ron van Kampen <Ron.van.Kampen@fel.tno.nl>
Subject: summary of position for ORI workshop
To: dchodge@BRL.MIL
Date: Thu, 16 Apr 92 16:58:31 MET DST
X-Mailer: ELM [version 2.3 PL11]

Position summary

Personal introduction

My name is Ron van Kampen and I am born on january 16, 1960. I studied computer science at the Delft University of Technology, where I graduated in 1983. On January 1, 1984 I started working for the Defence Research division of the Netherlands organization of applied scientific research (TNO), where I am currently responsible for the research activities in the area of (semi-) autonomous systems. TNO is a fully independent R&D organization with a staff of about 5200 and a total turnover of more than 250 million ECU a year. TNO is a member of the European Association of Contract Research Organizations (EACRO).

Summary of Position of D.J. Barrett,
DRA Malvern, UK for RSG-18 Workshop on Critical ORI Issues

27-29 Oct 92

SubGroup SG-4 Low Bandwidth Platforms

1. Personal Introduction.

My name is David Barrett and I lead a section within CSE1 Division at the Defence Research Agency (DRA) at Malvern, UK. The DRA is an agency of the UK Ministry of Defence. CSE1 Division is responsible for Signal and Pattern Processing while my section is concerned with the Application of Image Processing Techniques. Other areas in CSE1 are concerned with long term research into algorithms and architectures, and my section draws on this research base, to provide solutions for particular applications.

2. Main Area of Interest/Research.

My main area of research has been with future image processing architectures, to provide as near to real time image processing as is feasible. Most of these systems have recently been Transputer based with associated DSP devices as appropriate. These have ranged from single transputer low power image processors with 256 x 256 pixel frame stores, to larger 17 transputer arrays, each having two 512 x 512 frame stores, with a multiple DSP front end.

Among other topics, Image Compression has been of interest over the last few years. Various schemes have been implemented, being mainly based on the Discrete Cosine Transform (DCT). The research has looked at passing TV pictures over 25 KHx bandwidth radio channels with as fast an update and as good a quality as possible. This has obvious applications with low bandwidth platforms.

3. Opinion of State of the Art.

A T800 transputer can implement a DCT image compression in software on a 256 x 256 pixel image at about the same rate that it can be sent over a 16 Kbit/sec communication link. This means that it can be implemented on a fairly standard frame grabber without any special hardware. It cannot, however, keep up with higher bandwidth channels. The imminent release of the T9000 transputer may change this situation. Recently a large amount of commercial research has been put into the development of compression systems for support of video phone and multi media systems. These are nearly all designed to use single or multiple 64 Kbit/sec ISDN communication paths and are mainly intended to fit into a PC chassis, although the chip sets are normally available separately. They implement the MPEG, JPEG or H261 standards for image compression/ transmissions which are mainly DCT based, but can have additional processing for motion compensation where appropriate. There are also chip sets available which implement a fractal based compression system. All of these systems could potentially be of use on low bandwidth platforms, but will probably need to be slowed down to match the available bandwidth. Other problems are likely to be encountered with the quality of the communications system, since these systems tend to require low error rate channels.

Very rapid advances are currently being made in this field, which therefore needs little additional research. Care needs to be taken to assess whether the performance claimed, will really be achieved in the particular environment in which a system is to be deployed.

4. Opinion of Critical Issues.

4.1. The most critical issue with any low bandwidth image transmission system is the available bandwidth and quality of the link.

4.1.1. The bandwidth sets the rate of update and the resolution of the transmitted image. Trade offs have normally to be made to provide an acceptable output for the particular application. If two way communication is possible then the system configuration can be changed during use to optimise the performance for the conditions encountered.

4.1.2. Quality of the communications link affects the data overhead that has to be employed to correct for transmission errors. A 100% overhead is not uncommon to cope with error rates above 1 in 10^3 thus halving the picture update rate that could be obtained with the raw compression system. Quick recovery from a severe error is also important in many applications, and is dependant on framing information being passed sufficiently frequently. Half duplex systems have additional problems associated with Rx/Tx change over times, which can add delays into the system.

4.2. Various compression systems are becoming commercially available, which have an advertised performance which appears to offer high update rates and high resolution. Great care must be taken to ensure that they are compatible with the link bandwidth and data error rate or the performance will be severely degraded or may not work at all. Additional hardware to provide a more compatible link interface is invariably required. The type of picture being viewed also has implications on the compression ratio that can be achieved in practice.

4.3. The MMI can be considerably enhanced if the operator can interactively optimise the update rate, field of view and resolution for the task in-hand.

4.4. Power consumption is sometimes critical in robotic applications. Typical consumptions for compression systems are 5 to 50 Watts which is often comparable or less than the radio Tx sending the data back.

RESEARCH STUDY GROUP-18 ON OPERATOR-ROBOT INTERACTION

Personal Background: Stephen C. Roehrig
Department Manager, 9616
Advanced Vehicle Development
Sandia National Laboratories

Sandia National Laboratories is a U.S. Department of Energy laboratory historically dedicated to applied engineering research and implementation within the nuclear weapons complex. Through the years, Sandia has expanded its scope and currently addresses a wide range of national security issues for a wide range of sponsors. Since joining Sandia, I have participated in the definition, design, and construction of a number of sophisticated electromechanical projects ranging from physical security components and systems, to advanced conventional munitions. These activities have ranged from research and development of proof-of-principle systems, to implementation and fielding of those systems.

As manager of Sandia's Advanced Vehicle Development Department, I oversee the research and development of a large number of remote and automated systems for a diverse set of customers. Within the robotics arena, our programs have stressed practical application of mobile robotic platforms to national security needs varying from automated security platforms, to battlefield reconnaissance robots, to nuclear accident mitigation. Based upon these applications and research programs, Sandia has developed a extensive robotic vehicle fleet ranging from a child's All Terrain Vehicle (ATV) through a military 5 ton, 6x6 truck. These platforms have stressed appropriate use of technology for the application and have, thus, utilized a wide spectrum of control systems from a BASIC oriented single-board microprocessor, to a hierarchical STD computer-based system, to a VME/VX Works based real-time operating system.

"Robotics" is a catch-all word for what is really systems integration of a number of different technologies as applied to a specific application in the appropriate manner. As the individual technologies (communications, computers, sensors, actuators, ...) have matured, the robotics' industry has seen a rapid growth into numerous arenas. As with any new technology, however, one of the major problems within the community is deciding what and how this integrated technology ought to be applied to what has previously been a human domain. Thus, in most cases, the technology has been more progressive than what has actually been implemented. Along with the lack of understanding of the exact role that a specific robot should fill, is a concurrent lack of requirements concerning how the robot (again a highly integrated system) ought to address optimization of the overall system (the robot) versus its individual components.

This lack of understanding is, perhaps, even more exaggerated when considering how a remote operator should interact with a robotic platform. Two schools of thought have developed which have tended to gravitate to the opposite ends of the teleoperation vs. telepresence spectrum: being driven by their perceived need for the amount of data which must be communicated from the robot to its operator, and the perceived consequences of communicating large bandwidths. The need for high bandwidth communications (and more complex operator interfaces) has, to date, been very subjective and appears to have been driven more by application specific needs than by a consensus of opinion of its usefulness for generic tasks. Sandia, with its drive to field

lower cost/lower technology robots, has gravitated towards low bandwidth, RF communications. This approach has oriented most of our mobile robots towards monocular-vision teleoperation where the remote operator is constantly in the loop. Our experience has shown that teleoperation, with the addition of "hidden" computer assisted functions, is quite adequate for performing a number of military missions. There are a number of tasks, however, where more extensive interfaces are desirable or critical to success. Much more research needs to be focused upon obtaining a better understanding of the remote operator's interface with the robotic platform and its sensors and tools. Unless a clear understanding of the cost/benefit of interface issues and technologies can be developed, robotics will continue to suffer.

Sandia's experience, in fielding and controlling multiple robots from a single console, has shown that there can often be a synergistic coupling between fielded robots that can be quite effective. This approach, however, forces system designers to evaluate the "economic versus effectiveness" tradeoff between more capable, individual robots versus fielding larger numbers of robots where capabilities may be divided among several cooperating robots. Again, it would appear as if we, as a community, have not focused enough attention on system level issues and have narrowed too quickly upon specific technical questions.

Finally, a number of researchers, including Sandia, are beginning to investigate computer-assisted remote operations. Sandia has referred to this as telemanagement. The intent of this approach is to utilize the ever increasing processing power of computers, coupled with world models and real-time sensory information, to allow the on-board system's "intelligence" to filter operator commands and to modify those commands to allow safer and higher performance robots. The operator remains in the control loop, but becomes more of a supervisor instead of a second by second controller. This approach has great potential towards allowing improved performance through even reduced bandwidth communications and control.

4

"Smart" Image Transmission Holds Promise for Tele-Robotics

Peter J. Burt
David Sarnoff Research Center
Princeton, NJ 08543-5300 U.S.A.

The ability of an operator to drive a remotely piloted vehicle depends, in large part, on the quality of the video he receives from the vehicle. If the field of view is too small, or the resolution too low, he is liable to become disoriented and fail to recognize critical aspects of the scene.

Video quality is a critical issue in current efforts to develop unmanned ground vehicles for tactical missions. To avoid detection by the enemy video transmission will be restricted to very low bandwidth channels. For example, a proposal to use a 16 kbps channel will require 4000 to 1 data reduction from standard video. Current state-of-the-art compression technology cannot provide the video quality required for teleoperation at such low data rates.

Next generation "smart" image transmission techniques, however, hold the promise for providing the compression needed for tactical robot missions. Smart techniques will incorporate computer vision within the compression system to *select* the most critical scene information for transmission, and to *augment* the compressed video with derived aids to the operator, such as the shape of the ground surface in the vehicle's path, and the location of obstacles.

System Framework

Current systems perform compression in three basic stages. These will continue to provide the foundation for future smart systems. First, the overall video sample rate is reduced by restricting the field of view, reducing the sample density (and resolution), and reducing frame rate. Second, redundancy is removed from the sampled video through a DCT or wavelet image transformation, motion adaptive frame differencing, and entropy encoding. Finally, samples are quantized to achieve further data reduction with some loss in fidelity.

Color is encoded in the same way as luminance, though at significantly lower spatial resolution. Stereo can be encoded either in the form of a difference image formed between each stereo pair, or as a derived depth map.

In applications to teleoperation it is expedient to divide the camera's field of view into a central *foveal region* and a surrounding *peripheral region*. The foveal region is directed at the road in front of the vehicle, and is transmitted at relatively high resolution, while the periphery extends either side of the road, and is transmitted at relatively low resolution. This scheme, which is analogous to the resolution of the human eye, provides both the high resolution needed to discriminate objects in the road, and the wide field of view needed to provide context for driving.

The Oak Ridge National Laboratory and the Human Engineering Laboratory have developed a low data rate transmission system for the Robotic Testbed Demo I program that includes most of the system components outlined above. The system is implemented within a pyramid framework to provide direct control of the compression parameters.

The Role of Computer Vision

Computer vision can be used to automatically analyze the scene in front of the unmanned vehicle, and based on this information, to guide and augment the video transmission. Example functions served by vision include:

Electronic image stabilization: Successive images in the video sequence are aligned electronically. At the vehicle this provides a basis for motion adaptive image compression. At the operator's control unit it removes the effects of camera bounce prior to display.

Frame interpolation: Motion analysis at the operator's control station is used to interpolate missing frames in the transmitted video, and to provide a perceptually smooth display to the operator.

Field-of-view augmentation: The operator's control unit accumulates scene information as the vehicle moves, and stores this information in an evolving *reference panorama*. The accumulated information is used to extend the field of view of current video as it is displayed to the operator.

Change-based compression: The vehicle's vision system also accumulates scene information in a reference panorama. Each new image frame is compared to the stored panorama and the

transmission system is directed to selectively update regions of critical change.

Moving hazard detection: Motion analysis on the vehicle detects other moving vehicles or personnel that present a potability for collision. The operator is alerted to hazards through an alarm, or through a graphical or color overlay on the displayed video. The system transmits additional resolution in regions indicated as potential hazards.

Obstacle detection: Motion parallax and/or stereo analysis on the vehicle are used to detect obstacles in the path of the vehicle.

Terrain shape recovery and rendering: Motion parallax and/or stereo analysis on the vehicle are used to estimate the shape and tilt of the ground in front of the vehicle. This is rendered graphically on the operator's display.

Stereo display: Motion parallax and/or stereo analysis are used to derive a range map for the scene. This is used represent and transmit stereo imagery efficiently.

Implementation

The smart transmission techniques outlined above have yet to be tested on teleoperated vehicles. Some will require significant advances in vision technology before they can be performed reliably, in real time, using practical hardware.

Important steps in this direction are being made, however, and initial implementations of basic smart transmission techniques will be possible in the near future. For example, Sarnoff has recently completed hardware that can perform motion and stereo estimation in real time, and align image frames. This device could provide essential analysis function for several smart vision functions. Analysis is implemented within a pyramid framework so can be combined in a natural way with the ORNL/HEL low bandwidth transmission system.

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SUBGROUP 5

MISSION MODULES MAN-MACHINE INTERFACE

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5

KEY PERSONNEL

NAME	André PREUMONT
BIRTHDAY	February 18, 1951
NATIONALITY	Belgian
POSITION	Professor of Mechanical Engineering and Robotics (since October 1987) at the Free University of Brussels.
EDUCATION	BSc Ingénieur Civil des Constructions Aéronautiques University of Liège (1973)
	PhD Docteur en Sciences Appliquées University of Liège (1981) Dissertation : "Analyse sismique du coeur d'un réacteur nucléaire PWR".

PREVIOUS POSITION

1985-1986	Visiting Professor at the Aerospace and Ocean Engineering Department of Virginia Polytechnic Institute and State University (USA).
1986-1987	Independent Consultant for Belgonucléaire and Lecturer at the University of Liège.

SCIENTIFIC PRIZES

1981	AILg Prize for his PhD dissertation
1983	International Vinçotte Prize for "his contribution to the seismic analysis of Nuclear Power Plants".
1987	Louis BAES Prize from the Belgian Academy for his work in Random Vibration.

PROFESSIONAL SOCIETIES

AIAA - ASME - SBM

BOOK

"Vibration Aléatoires et Analyse Spectrale"
(Presses Polytechniques Romandes à Lausanne, 1990)

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Department of Mechanical Engineering and Robotics

The department was established in October 1987. Currently the department consists of one professor and eight assistants, research engineers and visiting scientists.

The department is equipped with a network of workstations provided with various CAD software packages for finite elements analysis, control system design, drafting, etc.

The laboratory is provided with vibration test equipment and hard and software for real time digital control using DC and microcontrollers.

The department specializes in simulation and real time digital control of mechanical systems, robots and flexible structures. It is involved in several national and international projects funded by the Belgian National Science Foundation, the Ministry for Research and Technology, the EEC and NATO, in the following areas:

- random vibration and acoustic fatigue

- active damping of vibration and precision control of flexible structures

- mobile robots and walking machines.

A small six legs walking robot with rectangular architecture and two degrees of freedom per leg has been built. The first version of this hexapod was controlled by a personal computer while the second one has its own microcontroller on board. Attitude control and pit detection algorithms have been implemented using microswitches on the end of each leg. A gait study has been made in speed and stability. Some of the most important gaits were tested with success on the prototype. Among the six families of regular, symmetric and periodic gaits studied, forward wave gaits are the more stable.

A new hexapod with hexagonal architecture is currently being developed. Macro instructions can be sent to an on-board microcontroller that manages the whole robot. Each leg has three degrees of freedom actuated by DC servo-motors and is controlled by its own μc. Optical encoders and potentiometers, microswitches on the leg ends, one X-Y inclinometer and a rate-gyroscope bring necessary information for attitude control and obstacle detection on flat or rough ground. A simulation software is developed to test different gaits on various kinds of terrain.

5

General Bruno LE MOINE
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Subgroup 5 - Mission Modules MMI

THE DRONE AND THE CONCEPT OF FAMILY

Much has been said and written about the lessons to draw from the "Gulf War". The huge effort which was made then to save the lives of the soldiers of the Allied Forces invoved in this war will undoubtedly remain the marking point of this conflict. The importance which is now given to such a priority will influence the decisions to be taken in the future.

Since the fall of the Berlin Wall, important changes have occurred which affect the geo-strategic balance established during the cold war, whereas at the same time, the international economic situation does no longer enable to keep up the investments which used to be granted to ensure this balance. This political and economic situation has lead all the Western Countries to cut down their defence expenses. This reduction in the credits has a double effect:

On the one hand, the financial aspect being more than ever a decisive priority, important programmes are being reconsidered.

On the other hand, military forces are drastically reducing their numbers.

For all these reasons, the forthcoming programmes will have to obey two major objectives: low cost, and minimal need in skilled labor.

New weapon whose interest was fully demonstrated during recent conflicts, the drone, by its very concept, complies both with the first principle and with the two objectives mentioned above, and explains in this way the attraction it represents for military officers in many countries.

• • •

For a long time it has been debated over the cost of several systems based on dedicated-type drones compared to the cost of multi-purpose or multi-misison drones.

The advantage a multi-purpose/multi-mission drone offers in comparison with any other drone is undoubtedly the everyday feature which characterizes its design. As far as the maintenance is concerned, the savings on the system's logistic are quite important. In addition, the everyday feature of such drones allows mass-production and as a consequence reduced unit prices.

On the counterpart, the multi-purpose system drone has to be spacious and therefore be equipped with a cell whose size is adapted to the variety of the equipment which has to be taken on board. As a consequence, both the unit cost of production and the price of implementation rise. In additon to these costs there is also the development price which cannot easily be estimated. The cost of the lose or attrition of the multi-mision drone is one of the most critical issues of the question.

The best compromise would consist in developing a system devoted to several missions thanks to modularity. This attractive solution is however quite limited, since despite the progress made in technology, modularity is difficult to control when too much is used, especially as far as interfaces are concerned, and its costs rapidly reaches high figures. Besides, on operational ground, modularity is difficult to manage, since it often requires a logistic support which is not adapted to the mobility required.

The concept of a family of drones is then an attractive solution.

• • •

The term of "family of drones" refers to a group of drones whose characteristics are similar and equipped with many components, systems and equipments, but whose different types are devoted to specific missions. In European civil aviation the "Airbus family" is one of the best illustrations of such a group.

The everyday feature concerns mainly air vehicles, general avionics and the launch and recovery systems. What differs is the payload taken aboard as well as the possible mechanisms of adaptation to the existing systems.

The concept of family is preferable to a modular system. At the conceptual stage of the design, each drone shall be devoted to a specific mission which simplifies both the conception and consequently the use of the system on the front line of operations, while concentrating the effects of modularity on the plant.

In this way, a family of drones could be developed to fulfill attack, intelligence, support and training missions. The drones would be equipped with similar base cells, as well as with common propulsion, avionics and flight controls. They could be launched from the same canister and recovered with the same system if necessary. A similar control system or ground station could be designed for all these missions. Since the only differences are the payloads required for the different types of missions and the interface with the rest of the system, they could be integrated and tested in a factory environment before delivery. Such an approach enables the Armed Forces to have a common replacement system and as a consequence reduced logistic procedures for an extended range of missions.

The concept of family of drones can be adapted to the specific needs of the different Forces. Numerous common solutions can be applied to a system based on drones if, at the conceptual stage of the design, the specific requirement of the user are taken into consideration.

From the logistic point of view, the possibility of using a cell, a propulsion, servos and general avionics common to all the Armed Forces is a very attractive idea. Such a drone can then be stored, carried, and launched from the same canister which will be designed to be used as such by the three Forces.

• • •

The technological progress for the twenty years to come should not bring much changes in the principles of use of the drone, but it should enable a reduction of the costs. The procedures should also be simplified which will lead to a facility of use.

Mass production and cost reduction are closely linked. If the notion of low costs shall be integrated to the Research Studies, the latter shall be carried out having in mind mass-

production procedure, keeping as a rule the notion of family of drones and a standardization of the equipments produced for all the different Forces.

The drone is now one element of the equipment used in wartime and its development should increase in the forthcoming years. The emergence of this new weapon in the Armed Forces' equipment shall be prepared from now on by implementing a philosophy of use at the operational level. This philosophy must take into account the specificity of the three Forces to guide the Research Studies with optimal efficiency.

Within this frame, the concept of family of drones is an operational and financial solution which can be used as a basic principle.

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Position summary for Workshop on Critical QRI issues.

Name: Karen Carr
Position: Section Leader, Display Applications; Project Manager, Advanced Displays.
Organisation: Human Factors Department
Sowerby Research Centre
British Aerospace Plc
FPC 267, PO Box 5
Filton, Bristol, UK.
(Tel. 0272 366259; FAX 0272 363733)

Main area of interest/research:

The role of the Sowerby Research Centre is to conduct the basic long term research which will benefit the British Aerospace group of companies. In the Human Factors Department, one of our main activities is to identify what the ideal human factors specifications for a particular application would be, and then to identify acceptable compromises where technology does not permit the ideal specifications. In order to do this it is usually necessary to conduct research to produce the required data and human factors tools. I have been working mostly in the area of advanced displays and applications, studying with a team of researchers the following topics:

Information requirements and presentation formats. What are the perceptual cues needed to perform tasks? Our display media include head-mounted displays and large "panoramic" displays, and both low and high resolution information.

Display device optimisation. What are the optimum specifications for particular devices for particular tasks? We have been studying frequency requirements and aliasing problems in both the temporal and spatial domains. The issues involved in viewing virtual images, particularly accommodation problems, and the effects of partial binocular overlap in a stereo display have been studied.

Human Performance measurement in complex workstations. We are developing tools to help us evaluate performance in complex tasks and with complete systems. We have focused upon mental workload and situation awareness, and are developing our own in-house tools.

Interaction with advanced displays. We have experimental programmes under way examining the use of eye pointing as an interaction mode with various advanced displays, and investigating manual interaction in virtual environments. Manual interaction studies address both visual and tactual (ie. tactile, kinaesthetic, and haptic) cues.

Our applications include military and civil aviation, computer-aided engineering (CAE), telepresence, simulation.

My opinion on the state of the art:
My opinion is that ORI and MMI is generally far too technology-driven. A good example of this is given by the current interest in 'Virtual Reality' (VR), where the arrival of low cost technology has caused a surge in interest in these computer-environment interfaces. There is a danger that the desire to use this technology will detract from what should be the main human factors approach. The concept of a completely flexible interface which can be designed according to the needs of the individual operator and specific task is of course the goal of the human factors specialist. However, if we wish to aim for the best possible system, the identification of these needs should precede any consideration of technology. Only having identified the needs should we look for the appropriate technology. It is clear that there are a number of problems with the current VR technology, and it may be that this is not the technology which can provide the MMI we really need. In any case, we need to know which are the critical factors which would determine the success of the interface so that technological research and development can be driven by these factors.

My opinion of critical issues:
I believe the critical issues are:

-How do we measure human performance in complex tasks? Can we identify objective performance measures; do we need to model cognitive functions?

-Information requirements: perceptual and cognitive; for displays and control. We still do not have enough basic data about information requirements for "standard" tasks. We need to build up a data base and also to establish methods for identifying requirements for specific tasks. Particular attention to feedback is also required.

-Information enhancement. In many situations we can improve upon the available information, for example in tasks involving time delay or low bandwidth systems. How can we enhance information to improve operator performance, and how does this relate to training?

-Effects of technology limitations upon performance. Given that in many cases, and at least for some time, technology will not be able to provide the ideal interface, we need to establish trade-off values for operator performance with a range of specifications.

-Human factors integration. Much of the basic research to generate data and methods should already have been completed in order to provide an input to the systems currently under development. As this is not the case, and systems are being developed, human factors effort tends to be devoted to providing

the information for specific systems. Human factors effort is of course a limited resource and basic research is delayed because of the immediate requirements. This issue needs to be addressed, because without the basic data and methods, human factors effort will always have to be application specific, and hence very inefficient. Some efforts have been made to collect basic data for human factors application, but there is room for a great increase in the efficiency of human factors practice, perhaps through organised collaboration.

-Modelling human performance for intelligent unmanned systems, and allocation of function. How can we match the cognitive models in the operator and in the system.

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LTC Mark L. Swinson
Unmanned Ground Vehicle Joint Project Office
U.S. Army Missile Command
Redstone Arsenal, AL 35898

1. Personal Introduction:

a. Name and Organization. My name is Lieutenant Colonel Mark L. Swinson, U.S. Army. I am the Assistant Project Manager and Technical Director of the Unmanned Ground Vehicle Joint Project Office (UGV JPO), which is assigned to the U.S. Army Missile Command, Redstone Arsenal, Alabama, USA, 35898.

b. Background. I am a 1974 graduate of the United States Military Academy (USMA) at West Point, New York. I earned a Masters Degree in Mechanical Engineering from the University of Wisconsin at Madison, Wisconsin, in 1982, and a Ph.D. in Mechanical Engineering/Robotics from the University of Florida at Gainesville, Florida, in 1988. My military experience includes staff and command assignments with divisional armor and missile maintenance units, instructor duty at USMA, and Robotics Staff Officer (RSO) duties at the Headquarters, U.S. Army Training and Doctrine Command (TRADOC). My formal military training includes the Army Command and Staff College and the Program Management Course at the Defense Systems Management College. I also am a licensed Professional Engineer (P.E.).

2. Main area of interest/research:

As technical director of the flagship program in battlefield robotics, my main interest is in addressing those technical issues which are relevant to the fielding and support of an initial system, as well as those technologies essential to support the Pre-Planned Product Improvement (P3I) effort. Central to both of these efforts is the Control problem.

Much focus has been placed on the Communication problem associated with providing the necessary bandwidth in order to support sufficient telepresence for remote operations, particularly remote driving. While important, such focus needs to be made within the wider context of the overall Control problem.

Ground mobility is inherently a "wide bandwidth" control problem, based upon characteristic stability margins associated with conventional ground mobility platforms and typical military operational environments. At one extreme, the human operator is used as the "control computer" to directly input high bandwidth servo commands to the actuators onboard the remote vehicle. This generally transforms the designer's problem into a high bandwidth communications problem, since sufficient telepresence (usually video imagery) is required to successfully implement such a control scheme. Unfortunately, the low frequency end of the electromagnetic spectrum, which provides frequencies with the best propagation characteristics, is not only the most oversubscribed, but it is also the least able to carry the huge amounts of data

necessary to support real-time video imagery.

At the other extreme, one might fully automate the control tasks onboard the remote vehicle, hence largely obviating the communications bandwidth dilemma. However, this implies not only automating the inner most servo control loops, but the higher level, contextual understanding (cognitive) processes as well. Despite many advances in so-called "artificial intelligence," this approach remains highly problematic.

One compromise is to provide sufficient telepresence for contextual understanding, which at least is suggestive of a significantly reduced communications bandwidth requirement, while at the same time providing sufficient onboard automation to execute the supporting servo control of the actuators. So called "waypoint control," as is currently implemented on most unmanned aerial vehicles (UAVs), is an example of this approach. This control strategy is often referred to as "telesupervision." Rather than acting as a remote pilot, the UAV operator uses his innate ability to interpret mission orders in an environmental context and issue appropriate instructions, which the onboard processors then interpret and execute in order to realize closed loop control. Various initiatives to develop and implement a similar control regime for unmanned ground vehicles (UGVs) are ongoing.

3. Opinion on the state of the art:

The current state of the art will support the fielding and support of an initial, militarily significant UGV capability. Appropriate research and development will serve to further enhance the utility of unmanned systems.

4. Opinion of critical issues:

I believe that control function allocation represents the key issue in Operator-Robot Interaction. How best to allocate control responsibilities (i.e. letting humans do what they do best, while automating those tasks best performed by machines) will largely determine the pace and level of success achieved by our efforts to provide NATO forces with this important capability; the capability to keep military personnel "out of harm's way."

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AC/243 (Panel 8) RSG-18 on Operator-Robot Interaction

WORKSHOP ON CRITICAL ORI ISSUES
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CANDIDATE ROBOTIC VEHICLE MISSIONS

1. UNMANNED GROUND VEHICLES

A. FIELD ARTILLERY

(1) ADVANCED FIELD ARTILLERY SYSTEM - Howitzer capable of autonomous/semi-autonomous operations on a battlefield. Capable of onboard fire direction, autoloading, automatic refueling, automatic missions selection, self locating and remote positioning.

(2) BATTALION TARGETING SYSTEM - Provides the battalion commander with real-time intelligence in his area of operations. System may employ aerial or land unmanned systems (UAV or UGV) to acquire data.

(3) FORWARD OBSERVER REMOTE TARGET ACQUISITION SYSTEM - This consists of a mission module that can be employed remotely to perform artillery forward observer functions through the use of a teleoperated vehicle.

B. ENGINEER

(4) OBSTACLE/MINEFIELD BREACHING SYSTEM - Ground vehicle platform capable of manned operation, teleoperated control and limited autonomous operation. The platform is capable of carrying a breaching system.

C. MILITARY POLICE

(5) MOBILE DETECTION AND RESPONSE SYSTEM - A surveillance/physical security module will be employed atop a mobile base. The mobile base may have some level of autonomy.

D. LOGISTICS

(6) FIELD MATERIAL HANDLING ROBOT - Intended for handling ammunition at various levels of supply points through the theater. Can autonomously acquire pallets of ammunition, pick them up and move them to various locations in a work cell type environment.

(7) FORWARD AMMUNITION RESUPPLY VEHICLE - A system for automatic resupply of armored vehicles. Capable of transloading from resupply vehicle to weapon platform.

Enclosure 4

(8) CLASS IX RESUPPLY SYSTEM - A robotic system that restacks palletized PLL (pre-loaded logistics) containers for company-sized customers. A fully autonomous system will include such device on airplanes and ships for packaging containers for combat units in the field.

E. TRANSPORTATION

(9) REMOTE CONVOY "TRAINING WHEELS" - A leader/follower system where a number of driverless vehicles follow a lead vehicle in a convoy. Could be used in a training environment to simulate the advance of large enemy forces with a minimum of personnel requirements.

(10) AUTOMATED HIGHWAY MONITORING POINTS - System that will provide realtime movement control information on the battlefield to the MCC (Movement Control Command).

F. CHEMICAL

(11) REMOTE SMOKE GENERATION SYSTEM - Smoke generation mission module attached to an unmanned vehicle for delivering smoke obscurants well forward of secure lines.

(12) REMOTE RECONNAISSANCE, DETECTION AND IDENTIFICATION VEHICLE - A small unmanned platform capable of conducting route, area and/or point NBC reconnaissance. Takes samples, marks contamination, provides early warning of chemical attach.

(13) ROBOTIC DECONTAMINATION DEVICE - A system capable of decontaminating a large number of tactical vehicles automatically.

G. COMMUNICATIONS

(14) REMOTE TRANSFER SYSTEM - A communication retransmission package to be deployed on a remotely operated or autonomous vehicle.

H. INFANTRY

(15) UNMANNED GROUND VEHICLE - Teleoperated unmanned ground system used to perform reconnaissance, intelligence, surveillance and target acquisition functions.

I. ARMOR

(16) REFUELING SYSTEM - A system capable of refueling armored vehicles under enemy small arms fire and/or artillery threats.

J. ORDNANCE

(17) AUTOMATED AMMUNITION RESUPPLY - System which can rapidly and autonomously load and unload palletized ammunition.

(18) AUTONOMOUS COMBAT EVACUATION VEHICLE - Robotic arms mounted on wheeled and tracked recovery vehicles to assist in hooking up tow arms or cables.

K. AVIATION

(19) UNMANNED FORWARD ARMING AND REFUEL POINT - System provides for unmanned refueling and rearming of aircraft.

L. AVIATION LOGISTICS

(20) UNMANNED AIRCRAFT RECOVERY VEHICLE - System capable of recovery of aircraft in forward areas. It will reduce the number of personnel exposed to hazards and allow for faster, safer recovery.

(21) UNMANNED AIRCRAFT DECONTAMINATION SYSTEM - Robotic system which can test and decontaminate aircraft using minimal or no personnel.

2. UNMANNED AERIAL VEHICLES

A. RECONNAISSANCE VEHICLE

Designed to gather real-time information about tactical targets using electro-optical (EO) and/or forward looking infrared (FLIR) detectors.

B. COMMUNICATIONS RELAY

Provides over-the-hill communications for line-of-sight radio systems.

C. ELECTRONIC WARFARE

Consists of CIN/CCM modules to jam enemy radars and to render ineffective adversaries' jamming techniques.

D. DECOY

A system designed to look like a tactical or strategic aircraft on enemy radars.

E. TARGETS

A class of systems that provide realistic training for manned systems using live weapons (guns and missiles).

F. ENVIRONMENTAL SAMPLING

Sensor systems with NBC sensors to provide early detection of attack by these weapons.

G. DRUG INTERDICTION

A surveillance mode that may provide wide area surveillance against low flying aircraft.

H. BATTALION TARGETING SYSTEM

Provides the battalion commander with real-time intelligence in his operational area.

I. FULL SCALE AERIAL TARGETS

Usually converted manned aircraft that provide realistic encounters for manual systems.

J. TARGET ACQUISITION

A system that can locate, mark and track a target for human-fired lethal munitions.

K. LOGISTICS SUPPLY SYSTEMS

Consist of heavy lift aerostats (blimps) that can perform resupply missions.

L. TRAINING

Surrogate UAVs that provide real-time realistic training for lethal man-in-the-loop systems.

M. RESEARCH

Test vehicles for hypersonic flight profiles.

N. UAV CLASSES

Very Low Cost:
- Inexpensive
- Man transportable
- May be expendable
- Range: a few km
- Payloads: 1-2 kg
- Endurance: 1-2 hours.

Close Range:
- Range: < 30 km
- Payloads: ≈ 10 kg
- Endurance: a few hours

Short Range:
- Range: to 150 km
- Payloads: ≈ 10 kg
- Endurance: up to 12 hours

Medium Range:
- Faster
- Range: up to 650 km
- Endurance: ≈ 5 hours

Endurance:
- High altitude
- Range: 1000 km
- Endurance: up to 6 days

3. SEA MISSIONS

A. MINE COUNTERMEASURES (MCM)

B. ANTI-SUMARINE WARFARE (ASW)

(1) BI-STATIC SONAR TRANSMITTER

Bi-static sonar transmitter. Working with an SSN on slow speed patrol. Separation be to studied. Sonar operating at about 1 kHz (material effects of charges to be studied) with an acoustic or fibre optic command link. Vehicle to be recovered after predetermined time on patrol.

(2) SUBMARINE ADVANCE SCREEN (PASSIVE)

Autonomous underwater vehicle (AUV) operating in concert with a forward operating SSN, possibly under ice, to identify enemy defensive SSN/SSK patrols. Action in event of contact, possibly use a fibre optic data link with onboard back-up.

C. TRAINING

(1) SONAR TARGET

An AUV submarine simulator for surface ship training. It must produce realistic active (highlight) and passive signatures and respond realistically to the actions of the trainee. Also necessary is a comprehensive onboard data/event logger for post-trial analysis. A command link for backup mission control/update is required.

(2) WEAPON TARGET (TORPEDO)

AUV to replace real vessels as targets, particularly during torpedo development and acceptance. It must compensate for small size by including accurate miss distance indicator.

D. INTELLIGENCE DATA GATHERING

E. MINING

(1) MOBILE OFFENSIVE DELIVERY

A submarine launched vehicle to deliver a mine/mines to a forward offensive location.

E. VESSEL LAUNCHED DECOYS AND COUNTERMEASURES

(1) WAKE HOMING SOFT KILL

The AUV or AUVs are deployed to generate a false ship wake to deceive a beam-fired wake homing torpedo. The deployment would be made in response to alerted threat rather than a patrol condition and the vehicle must be regarded as expendable if it successfully attracts the attentions of a torpedo.

F. ANTI-SURFACE VESSEL & ANTI-AIR WARFARE (ASVW/AAW)

(1) ECM/ESM/ELINT.

Submarine-launched vehicle to deploy aerials at surface (RX and TX) for a variety of EW roles. Operational scenario TBD. The vehicle must be recoverable by the submarine.

G. SUPPORT ACTIVITIES (E.G., SIGNATURE MEASUREMENT, MAINTENANCE)

(1) ACOUSTIC SIGNATURE MEASUREMENT.

An AUV based acoustic signature measurement "range" for use by a force operating our of area and away from normal noise range support. Other influences (magnetic, electric) could be included as appropriate.

(2) ACOUSTIC PROPAGATION

Two vehicles to conduct non-covert acoustic propagation trials in open sea areas, e.g., strategic ocean fronts, etc. Vehicles to be surface launched. The relative navigation and positions of the two vehicles must be known very accurately, but a constant precise knowledge of their absolute positions is less important.

•The receiving vehicle will contain the recorded data and AI to maintain command; it must be recovered at the end of the trial. It is seen as an intelligent but slave vehicle, responding to the actions of the transmitter to maintain the mission profile.

•The transmitting vehicle is seen as a functional, relatively unsophisticated vehicle and could be expendable under some circumstances. It acts as the master vehicle in that its actions determine the actions of the receiver.

(H) SPECIAL OPERATIONS

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